NİĞDE ÖMER HALİSDEMİR UNIVERSITY 1992

1ST INTERNATIONAL DIGITAL AGRICULTURE Congress

INDAC 2025

NİĞDE / TÜRKİYE

ON BEHALF OF **PROF. DR. HASAN USLU**

18-20 SEPTEMBER 2025

10.00

NÖHÜ Şehit Ömer Halisdemir Congress and Cultural Center

www.indac.com.tr

Mail: indac@indac.com.tr

PROCEEDING BOOK

978-625-97746-5-7

PREFACE

Dear Colleagues,

The "1st International Digital Agriculture Congress (INDAC 2025)" was held in Niğde/ Turkey on September 18-20, 2025, with the participation of scientists working in agriculture and related scientific fields. The aim was to share scientific developments, propose scientific solutions to international problems, increase collaborations, and create scientific outputs that will benefit humanity through the economical use of international resources.

99 papers were presented at our congress from 14 countries. 57 of these papers were from abroad and 42 were from Türkiye. The countries of the participants who submitted papers to the congress and the number of papers received are as follows; Algeria (10), Bangladesh (3), China (6), Iran (2), Nigeria (14), Pakistan (10), Costa Rica (1), Sri Lanka (1), Sudan (4), USA (5), Tunisia (2), Uzbekistan (1), Turkey (42) and Arabia (1). The rate of foreign participants in our congress was determined to be 58%.

At the congress; unique and advanced technologies related to agriculture and natural life; animal production, plant production, aquaculture, food science and technologies, agricultural technologies, soil science, sustainable agricultural systems, agricultural economics, genetics, biology, agricultural ecology, landscape architecture, and agro-environment issues were discussed by the participants.

Prof. Dr. Hasan USLU, Prof. Dr. Ahmet ŞEKEROĞLU, Prof. Dr. Hasan ELEROĞLU, Assoc. Prof. Dr. Burak ŞEN, Dr. Mustafa DUMAN, Ahmet AKYOL, Furkan BAŞ, Dr. Ali Kaan YETIK, Muhammet Talha İNCE, Suden Nur YÜKSEL, and Şeyda Yağmur ÜREN undertook roles in the organization and execution of our congress.

We would like to express our gratitude to all our stakeholders who did not withhold their support in the successful realization of our congress, and to all the scientists who supported us by participating with their presentations.

The Rectorate has approved the appointment of the faculty members and stakeholders listed in the attached document as Academic Representatives on the Congress Organizing Committee at the 1st International Digital Agriculture Congress (INDAC 2025), organized by the Turkish Science and Technology Publications (TURSTEP), hosted by Niğde Ömer Halisdemir University, in collaboration with Cumhuriyet University and the Ayhan Şahenk Agricultural Application and Research Center Directorate, and bringing together sector representatives, growers, and researchers between September 18-20, 2025.

Sincerely.

ÖNSÖZ

Sayın Meslektaşlarımız,

Tarım ve ilgili bilim dallarında çalışan bilim insanlarının katılımıyla, bilimsel gelişmeleri paylaştıkları, uluslararası sorunlara bilimsel çözümler önermek, iş birliklerini artırarak uluslararası kaynakların ekonomik kullanılmasıyla insanlığın yararına olacak bilimsel çıktıların oluşturulması amacıyla, 18-20 Eylül 2025 tarihinde Niğde/Türkiye'de "1. Uluslararası Dijital Tarım Kongresi (INDAC 2025)" gerçekleştirilmiştir.

Kongremize 14 ülkeden 99 bildiri sunulmuştur. Bu bildirilerin 57'i yurt dışından, 42'ı ise Türkiye'den gelmiştir. Kongreye bildiri gönderen katılımcıların ülkeleri ve gelen makale sayıları şu şekildedir; Algeria (10), Bangladesh (3), Çin (6), Iran (2), Nigeria (14), Pakistan (10), Costa Rica (1), Sri Lanka (1), Sudan (4), USA (5), Tunus (2), Uzbekistan (1), Türkiye (42) ve Arabistan (1). Kongremizdeki yabancı katılımcı oranı %58 olarak tespit edilmiştir.

Kongrede; tarım ve doğal hayat ile ilgili özgün ve ileri teknoloji ile ilgili; hayvansal üretim, bitkiselüretim, su ürünleri, gıda bilimi ve teknolojileri, tarım teknolojileri, toprak bilimi, sürdürülebilirtarım sistemleri, tarım ekonomisi, genetik, biyoloji, tarımsal ekoloji, peyzaj mimarlığı ve tarımsalçevre konuları katılımcılar tarafından tartışılmıştır.

Kongremizin düzenlenmesi ve kongre aşamasında; Prof. Dr. Hasan USLU, Prof. Dr. Ahmet ŞEKEROĞLU, Prof. Dr. Hasan ELEROĞLU, Doç. Prof. Dr. Burak ŞEN, Dr. Mustafa DUMAN, Ahmet AKYOL, Furkan BAŞ, Dr. Ali Kaan YETIK, Muhammet Talha İNCE, Suden Nur YÜKSEL, Şeyda Yağmur ÜREN görevler üstlenmişlerdir. Kongremizin başarılı bir şekilde gerçekleştirilmesinde desteklerini esirgemeyen tüm paydaşlarımıza ve bildirileri ile katılarak destek veren tüm bilim insanlarına teşekkürü bir borç biliriz.

Türk Bilim ve Teknoloji Yayımları (TURSTEP)'nın Koordinatörlüğünde, Niğde Ömer Halisdemir Üniversitesi ev sahipliğinde, Cumhuriyet Üniversitesi ve Ayhan Şahenk Tarımsal Uygulama ve Araştırma Merkezi Müdürlüğü işbirliğiyle, sektör temsilcilerinin, yetiştiricilerin ve araştırmacıların; 18-20 Eylül 2025 tarihleri arasında düzenlenmiş olan 1. Uluslararası Dijital Tarım Kongresi'nde (INDAC 2025) ilgi yazı ekinde belirtilen öğretim elemanlarının ve paydaşarın Kongre Düzenleme Kurulunda Akademik Temsilci olarak görevlendirilmeleri rektörlüğümüzce uygun bulunmuştur.

Saygılarımızla.

Assoc. Prof. Dr.	Mehmet Metin ÖZGÜVEN	Ankara University	Turkey
Assoc. Prof. Dr.	Yonis GULZAR	King Faisal University	Saudi Arabia
Assoc. Prof. Dr.	Zeynep ÜNAL	Niğde Ömer Halisdemir University	Turkey
Assoc. Prof. Dr.	Burak ŞEN	Niğde Ömer Halisdemir University	Turkey
Assoc. Prof. Dr.	M. Emin BİLGİLİ	Eastern Mediterranean Agricultural Research Institute	Turkey
Assoc. Prof. Dr.	İlker İNAL	Eastern Mediterranean Agricultural Research Institute	Turkey
Assoc. Prof. Dr.	Aydın ALTOP	Ondokuz Mayıs University	Turkey
Assist. Prof. Dr.	Tefide KIZILDENIZ GÜRBÜZ	Niğde Ömer Halisdemir University	Turkey
Assist. Prof. Dr.	Uzair Aslam BHATTI	Hainan University	China
Assist. Prof. Dr.	Allah BAKHSH	University of the Punjab	Pakistan
Assist. Prof. Dr.	Abdul Qayoom HAMAL	Birmingham City University	UK
Assist. Prof. Dr.	Serap GÖRÜCÜ	University of Florida	USA
Assist. Prof. Dr.	Marcelle Michelotti BETTONI	Independent consultant of Agriculture	Brasil
Dr.	İbrahim CERİT	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Dürdane MART	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Hilal YILMAZ	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	C. Aylin OLUK	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Prem SHARMA	CTA of Natural Resources/Management UN FAO (Retired)	India
Dr.	Hümeyra YAMAN	Field Crops Central Research Institute	Turkey

SCIENTIFIC COMMITTEE of the CONGRESS

Title	Name Surname	Institute	Country
Prof. Dr.	Ahmet ŞEKEROĞLU	Niğde Ömer Halisdemir University	Turkey
Prof. Dr.	Hasan TANGÜLER	Niğde Ömer Halisdemir University	Turkey
Prof. Dr.	Adnan ÜNALAN	Niğde Ömer Halisdemir University	Turkey
Prof. Dr.	Mustafa AVCI	Niğde Ömer Halisdemir University	Turkey
Prof. Dr.	Hasan ÖNDER	Ondokuz Mayıs University	Turkey
Prof. Dr.	İsmail BÖREKÇİ	Aydın Adnan Menderes University	Turkey
Prof. Dr.	Zeki BAYRAMOĞLU	Selçuk University	Turkey
Prof. Dr.	Çiğdem TAKMA	Ege University	Turkey

Prof. Dr.	Hasan ELEROĞLU	Cumhuriyet University	Turkey
Prof. Dr.	Sedat KARAMAN	Gaziosmanpasa University	Turkey
Prof. Dr.	Zeliha SELAMOĞLU	Niğde Ömer Halisdemir University	Turkey
Prof. Dr.	Zeynel CEBECI	Çukurova University	Turkey
Prof. Dr.	Ali Osman DEMIR	Uludağ University	Turkey
Prof. Dr.	Harun KAMAN	Akdeniz University	Turkey
Prof. Dr.	Metin SEZEN	Çukurova University	Turkey
Prof. Dr.	Raheel NAWAZ	Staffordshire University	UK
Prof. Dr.	Luis Godoy MONTIEL	Quevedo State Technical University	Ecuador
Prof. Dr.	Carlos Robles ROJAS	Instituto Tecnologico de Costa Rica	Costa Rica
Prof. Dr.	Oscar Octavio Fernández CUTIRE	University National Jorge Basadre Grohmann	Peru
Prof. Dr.	Francisco Teodoro Condori TINTAYA	University National Jorge Basadre Grohmann	Peru
Prof. Dr.	Mosaad A. ABDEL-WAHHAB	Food Toxicology & Contaminants Dept., National Research Centre	Egypt
Prof. Dr.	Benoudnine HADJIRA	Abdelhamid Ibn Badis University	Algeria
Prof. Dr.	Mirza Barjees BAIG	King Saud University	Saudi Arabia
Assoc. Prof. Dr.	Aidin Azizpour	University of Mohaghegh Ardabili	Iran
Assoc. Prof. Dr.	Cem BALTACIOĞLU	Niğde Ömer Halisdemir University	Turkey
Assoc. Prof. Dr.	Fatih Çağatay BAZ	Osmaniye Korkut Ata University	Turkey
Assoc. Prof. Dr.	Ekrem MUTLU	Kastamonu University	Turkey
Assoc. Prof. Dr.	Emre ŞİRİN	Ahi Evran University	Turkey
		Malatya Turgut Özal University	Turkey
Assoc. Prof. Dr.	Yeşim BOZKURT ÇOLAK		
Assoc. Prof. Dr.	Burak ŞEN	Niğde Omer Halisdemir University	Turkey
Assoc. Prof. Dr.	İlker İNAL	Eastern Mediterranean Agricultural Research Institute	Turkey
Assoc. Prof. Dr.	M.Emin BİLGİLİ	Eastern Mediterranean Agricultural Research Institute	Turkey
Assoc. Prof. Dr.	Hatun BARUT	Eastern Mediterranean Agricultural Research Institute	Turkey
Assoc. Prof. Dr.	Gönül CÖMERTPAY	Eastern Mediterranean Agricultural Research Institute	Turkey
Assoc. Prof. Dr.	Hatice HIZLI	Eastern Mediterranean Agricultural Research Institute	Turkey
Assist. Prof. Dr.	Brian TAINIKA	Niğde Omer Halisdemir University	Turkey
Assist. Prof. Dr.	Mustafa DUMAN	Niğde Omer Halisdemir University	Turkey
Assist. Prof. Dr.	Emre AKSOY	Middle East Technical University	Turkey
Assist. Prof. Dr.	Allah BAKHSH	University of the Punjab	Pakistan
Assist. Prof. Dr.	Kadir ERENSOY	Ondokuz Mayıs University	Turkey

Assist. Prof. Dr.	Gulnur SULEIMANOVA	Kazakh National Agrarian Research University	Kazakhstan
Assist. Prof. Dr.	Bruna RAMALHO	Universidade Federal do Paraná	Brazil
Assist. Prof. Dr.	Aneela AFZAL	Pir Mehar Ali Shah Arid Agriculture University	Pakistan
Assist. Prof. Dr.	Marcelle Michelotti BETTONI	Independent consultant of Agriculture	Brazil
Dr.	Muhammad Habib-ur-RAHMAN	Georg-August-University of Göttingen	Germany
Dr.	Chadha AYED	High Agronomic Institute of Chott-Mariem, University of Sousse	Tunisia
Dr.	Neji TARCHOUN	High Agronomic Institute of Chott-Mariem, University of Sousse	Tunisia
Dr.	Riadh ILAHY	National Agricutrural Research Institute of Tunisia, University of Carthage	Tunisia
Dr.	Nabeel KAEAT	College of Agriculture, University of Al-Muthanna	Iraq
Dr.	Malik H. KAREM	College of Agriculture, AL-Muthanna University	Iraq
Dr.	Ahmed Shamhi JABBAR	University of Al-Qadisiyah	Iraq
Dr.	Hümeyra YAMAN	Field Crops Central Research Institute	Turkey
Dr.	Fatma Gül MARAŞ VANLIOĞLU	Field Crops Central Research Institute	Turkey
Dr.	Yavuz DELEN	Field Crops Central Research Institute	Turkey
Dr.	Dürdane MART	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Ayşe Nuran ÇİL	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	A. Alparslan EZİCİ	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Serdal ÇOBAN	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Hilal YILMAZ	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	C. Aylin OLUK	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Pınar ÇUBUKÇU	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Bülent ÇAKIR	Eastern Mediterranean Agricultural Research Institute	Turkey

Dr.	Hasan AY	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Nurten KURT	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Meltem TÜRKERİ	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Selma KAYA	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Ahmet Korhan ŞAHAR	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Hasan MUTLU	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Fulya SERT	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Senem ÖZKAYA	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Nergiz ÇOBAN	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Dürdane MART	Eastern Mediterranean Agricultural Research Institute	Turkey
Dr.	Ali Kaan Yetik	Niğde Ömer Halisdemir University	Turkey

INVITED DECLARATIONS

Title	Name Surname	Institute	Country
Prof. Dr.	Zeynel CEBECI	Çukurova University	Turkey
Prof. Dr.	Zeki BAYRAMOĞLU	Selçuk University	Turkey
Assoc.Prof.	Nikolay BLIZNYUK	University of Florida	USA

ULUSLARARASI KONGRE ÖZELLİKLERİ

1.Bilim kurulunda yer alan yurt dışından akademisyenler

Title	Name Surname	Institute	Country
Prof. Dr.	Raheel NAWAZ	Staffordshire University	UK
Prof. Dr.	Luis Godoy MONTIEL	Quevedo State Technical University	Ecuador
Prof. Dr.	Carlos Robles ROJAS	Instituto Tecnologico de Costa Rica	Costa Rica
Prof. Dr.	Oscar Octavio Fernández CUTIRE	University National Jorge Basadre Grohmann	Peru
Prof. Dr.	Francisco Teodoro Condori TINTAYA	University National Jorge Basadre Grohmann	Peru
Prof. Dr.	Mosaad A. ABDEL-WAHHAB	Food Toxicology & Contaminants Dept., National Research Centre	Egypt
Prof. Dr.	Benoudnine HADJIRA	Abdelhamid Ibn Badis University	Algeria
Prof. Dr.	Mirza Barjees BAIG	King Saud University	Saudi Arabia
Assoc. Prof. Dr.	Aidin Azizpour	University of Mohaghegh Ardabili	Iran
Assist. Prof. Dr.	Allah BAKHSH	University of the Punjab	Pakistan
Assist. Prof. Dr.	Gulnur SULEIMANOVA	Kazakh National Agrarian Research University	Kazakhstan
Assist. Prof. Dr.	Bruna RAMALHO	Universidade Federal do Paraná	Brazil
Assist. Prof. Dr.	Aneela AFZAL	Pir Mehar Ali Shah Arid Agriculture University	Pakistan
Assist. Prof. Dr.	Marcelle Michelotti BETTONI	Independent consultant of Agriculture	Brazil
Dr.	Muhammad Habib-ur-RAHMAN	Georg-August-University of Göttingen	Germany

Dr.	Chadha AYED	High Agronomic Institute of Chott-Mariem, University of Sousse	Tunisia
Dr.	Neji TARCHOUN	High Agronomic Institute of Chott-Mariem, University of Sousse	Tunisia
Dr.	Riadh ILAHY	National Agricutrural Research Institute of Tunisia, University of Carthage	Tunisia
Dr.	Nabeel KAEAT	College of Agriculture, University of Al-Muthanna	Iraq
Dr.	Malik H. KAREM	College of Agriculture, AL-Muthanna University	Iraq
Dr.	Ahmed Shamhi JABBAR	University of Al-Qadisiyah	Iraq

2.Kongreye katılım sağlanan ülkeler ve bildiri sayıları

SN	Ülke	Bildiri Sayısı
1	Algeria	10
2	Bangladesh	3
3	China	6
4	Iran	2
5	Nigeria	14
6	Pakistan	10
7	Sri Lanka	1
8	Sudan	4
9	Tunisia	2
10	Türkiye	42
11	USA	5
12	Uzbekistan	1
13	Arabistan	1

T.C.
NİĞDE ÖMER HALİSDEMİR ÜNİVERSİTESİ REKTÖRLÜĞÜ
Personel Daire Başkanlığı

2025 AİLE YILI

Sayı : E-87795264-900-706459 12/09/2025
Konu : INDAC 2025 Kongresine Akademik Temsilci Görevlendirme Talebi

TARIM BİLİMLERİ VE TEKNOLOJİLERİ FAKÜLTESİ DEKANLIĞINA

İlgi : 12/09/2025 tarihli ve E-55340578-903.07-706288 sayılı yazınız.

Türk Bilim ve Teknoloji Yayımları (TURSTEP)'nın Koordinatörlüğünde, Üniversitemiz ev sahipliğinde, Cumhuriyet Üniversitesi, Üniversitemiz Ayhan Şahenk Tarımsal Uygulama ve Araştırma Merkezi Müdürlüğü ile Fakülteniz işbirliğiyle, sektör temsilcilerinin, yetiştiricilerin ve araştırmacıların katılımıyla 18-20 Eylül 2025 tarihleri arasında düzenlenecek olan 1. Uluslararası Dijital Tarım Kongresi'nde (INDAC 2025) ilgi yazınız ekinde isimleri belirtilen öğretim elemanlarının Kongre Düzenleme Kurulunda Akademik Temsilci olarak görevlendirilmeleri Rektörlüğümüzce uygun bulunmuştur.

Gereğini rica ederim.

Prof. Dr. Hasan USLU
Rektör

Bu belge, güvenli elektronik imza ile imzalanmıştır.

Belge Doğrulama Kodu: BS589T84UN

Adres:Merkez Yerleşke Bor Yolu 51240 Niğde
Telefon:0 388 225 26 71 Faks:0 388 225 26 70
e-Posta:personeldb@ohu.edu.tr Web:www.ohu.edu.tr
Kep Adresi:nohu@hs01.kep.tr

Bilgi için: Hatice Altındal
Unvanı: Bilgisayar İşletmeni
Tel No: 2675

T.C.
NİĞDE ÖMER HALİSDEMİR ÜNİVERSİTESİ REKTÖRLÜĞÜ
Tarım Bilimleri ve Teknolojileri Fakültesi Dekanlığı

Sayı : E-55340578-903.07-706288 12/09/2025
Konu : INDAC 2025 Kongresine Akademik Temsilci Görevlendirme Talebi

REKTÖRLÜK MAKAMINA
(Personel Daire Başkanlığı)

Fakültemiz Biyosistem Mühendisliği Bölümü Öğretim Üyesi Doç. Dr. Burak ŞEN'in, 18-20 Eylül 2025 tarihleri arasında düzenlenecek olan '1. Uluslararası Dijital Tarım Kongresi'nde (INDAC 2025) ekte belirtilen akademik personelin "Kongre Düzenleme Kurulunda Akademik Temsilci" olarak görevlendirilmeleri talebine ilişkin dilekçesi ve bölüm başkanlığının yazısı ilişikte sunulmuştur.

Gereğini arz ederim.

Prof. Dr. Ahmet ŞEKEROĞLU
Dekan V.

Ek:Bölüm Başkanlığı'nın Yazısı ve Ekleri (3 Sayfa)

Adres:Merkez Yerleşke Bor Yolu 51240 Niğde
Telefon:3882254446 Faks:3882254440
e-Posta:tbtf@ohu.edu.tr Web:www.ohu.edu.tr
Kep Adresi:nohu@hs01.kep.tr

Bilgi için: Öznur KILINÇARSLAN
Unvanı: Bilgisayar İşletmeni
Tel No: 0 388 225 4446

T.C.
NİĞDE ÖMER HALİSDEMİR ÜNİVERSİTESİ REKTÖRLÜĞÜ
Tarım Bilimleri ve Teknolojileri Fakültesi Dekanlığı
Biyosistem Mühendisliği Bölüm Başkanlığı

2025 AİLE YILI

Sayı : E-94107266-900-705972 11/09/2025
Konu : INDAC 2025 Kongresi Akademik Temsilci

TARIM BİLİMLERİ VE TEKNOLOJİLERİ FAKÜLTESİ DEKANLIĞINA

Bölümümüz Öğretim Üyesi Doç.Dr.Burak ŞEN'in, 18-20 Eylül 2025 tarihleri arasında düzenlenecek olan "1. Uluslararası Dijital Tarım Kongresi'nde (INDAC 2025) ekte belirtilen akademik personelin "Kongre Düzenleme Kurulunda Akademik Temsilci" olarak görevlendirilmeleri talebine ilişkin dilekçesi yazımız ekinde sunulmuştur.

Gereğini arz ederim.

Doç. Dr. Burak ŞEN
Bölüm Başkanı

Ek:INDAC 2025 Kongresi Akademik Temsilci (2 Sayfa)

Adres:Merkez Yerleşke Bor Yolu 51240 Niğde
Telefon:3882254446 Faks:3882254440
e-Posta:tbtf@ohu.edu.tr Web:www.ohu.edu.tr
Kep Adresi:nohu@hs01.kep.tr

Bilgi için: Yasemin GÜNER
Unvanı: Bölüm Sekreteri
Tel No: 0 388 225 4470

BİYOSİSTEM MÜHENDİSLİĞİ BÖLÜMÜ BAŞKANLIĞINA

Konu : INDAC 2025 Kongresi Akademik Temsilci

Türk Bilim ve Teknoloji Yayımları (TURSTEP)'nın koordinatörlüğünde, Niğde Ömer Halisdemir Üniversitesi ev sahipliğinde, Cumhuriyet Üniversitesi, Niğde Ömer Halisdemir Üniversitesi Ayhan Şahenk Tarımsal Uygulama ve Araştırma Merkezi Müdürlüğü, Tarım Bilimleri ve Teknolojileri Fakültesi işbirliğiyle, sektör temsilcilerinin, yetiştiricilerin ve araştırmacıların katılımıyla 18-20 Eylül 2025 tarihleri arasında düzenlenecek olan "1. Uluslararası Dijital Tarım Kongresi'nde (INDAC 2025) ekte belirtilen akademik personelin "Kongre Düzenleme Kurulunda Akademik Temsilci" olarak görevlendirilmeleri hususunda; Gereğini arz ederim.

Kongre Sekreteryası Adına

Doç. Dr. Burak ŞEN
Öğretim Üyesi
11/09/2025

Ek:Ist International Digital Agriculture Congress akademik temsilci listesi (1 Sayfa)

Kep Adresi:nohu@hs01.kep.tr
Bilgi için: Burak ŞEN
Unvanı: Öğretim Üyesi
Tel No: 0 388 225 4455

Ist International Digital Agriculture Congress (INDAC 2025)

Düzenleme Kurulunda Akademik Temsilci Listesi

Prof. Dr. Hasan USLU (Kongre Sahibi)
Prof. Dr. Ahmet ŞEKEROĞLU (Düzenleyici)
Prof. Dr. Ayhan GÖKÇE
Prof. Dr. Gülden Sandal ERZURUMLU
Doç. Dr. Burak ŞEN
Doç. Dr. Hande BALTACIOĞLU
Doç. Dr. Cem BALTACIOĞLU
Doç. Dr. Khawar JABRAN
Doç. Dr. Zeynep ÜNAL
Doç. Dr. Tefide KIZILDENIZ GÜRBÜZ
Dr. Mustafa DUMAN
Dr. Ali Kaan YETIK
Arş. Gör. Furkan BAŞ
Arş. Gör. Ahmet AKYOL
Arş. Gör. Muhammet Talha İNCE

I. International Digital Agriculture Congress (INDAC)

18 September 2025

Niğde, Türkiye

Salon 1 / Hall 1

Yüz Yüze Katılım Programı / Face to Face

AÇILIŞ		**10:00**		**Açılış Konuşması, Protokol** Faruk AKBULUT Prof. Dr. Ahmet ŞEKEROĞLU Prof. Dr. Hasan USLU Dr. Cahit ÇELİK	Niğde İl Tarım ve Orman Müdür Yrd. Niğde Ömer Halisdemir Üniversitesi/Dekan Niğde Ömer Halisdemir Üniversitesi/Rektör Niğde Valisi (Teşrifleri halinde)	Türkiye
		10:40		Prof. Dr. Zeynel CEBECI (Çukurova University)	**Çağrılı Bildiri/ invited speaker** "Implementation of Artifical intelligence agents for strategic transformation in agriculture / Tarımda stratejik dönüşüm için yapay zeka ajanları geliştirme"	Türkiye
Mola / Break **11:00 – 11:20**						
Moderatör: Prof. Dr. Zeynel CEBECI **Congress Participation Link:** Genel | INDAC 2025 Çağrılı Konuşmacılar | Microsoft Teams						
Oturum **Session**	**Sıra** **No**	**Saat** **Time**	**ID**	**Yazar** **Authors**	**Çalışmanın Adı** **Paper Name**	**Ülke** **Country**
1	1	11:20		Prof. Dr. Zeki Bayramoğlu (Selçuk University)	**Çağrılı Bildiri/ invited speaker** "Teknoloji Kullanımı, Tarımda Dijitalleşmenin Önemi"	Türkiye
	2	11:40		Assoc.Prof. Nikolay BLIZNYUK University of Florida	**Çağrılı Bildiri/ invited speaker (Teams Connection)** "Statistical machine learning for improved detection and uncertainty quantification of pathogenic E. Coli in hydroponic irrigation water using impedimetric systems"	USA

Mola / Break 12:00 – 13:20						
	Moderatör: Prof. Dr. Zeki Bayramoğlu					
2	3	13:20	412	Şule Sancak	Electrocoagulation Applications İn Microplastic Removal From Sediment Environment	Türkiye
	4	13:40	523	Gülden Sandal Erzurumlu	Distribution and Utilization of Thymus sp. Species in Turkey	Türkiye
	5	14:00	453	Gökçe ÖZDEMİR	From Livestock 1.0 to Livestock 4.0: Digitalisation Adventure in Livestock: From Livestock 1.0 to Livestock 4.0: Digitalisation Adventure in Livestock	Türkiye
	6	14:20	454	Gökçe ÖZDEMİR	Precision Livestock Farming Practices in Cattle Breeding	Türkiye
Mola / Break 14:40 – 15:00 Congress Participation Link: Genel | INDAC 2025 Çağrılı Konuşmacılar | Microsoft Teams						
	Moderatör: Doç. Dr. Hande BALTACIOĞLU					
3	7	15:00	539	Yonis Gulzar	**Çağrılı Bildiri/ invited speaker (Teams Connection)** Smart Harvests: Deep Learning and the Future of Agriculture	Saudi Arabia
	8	15:20	479	Tefide Kızıldeniz, İremay Özalp	The Use Of Rose Plants As An Early Warning Indicator For Powdery Mildew (Erysiphe Necator) İn Viticulture And The Evaluation Of Image Processing-Based Applications	Türkiye
	9	15:40	452	Beyza YILMAZ, Ayhan CEYHAN	Use of Smart Technologies in Assessing Animal Welfare in Small Ruminant Breeding	Türkiye
	10	16:00	538	Murat İnan	ehalmal.com: Dijital Tarım Dönüşümünde İnovatif Bir Model ve Tarım Ekonomisine Etkileri	
	11	16:20	489	İlbilge Oğuz, Halil İbrahim Oğuz, Osman Gökdoğan, Nesibe Ebru Kafkas	Strawberry Cultivation Using Smart Systems	Türkiye
	12	16:40	490	Halil İbrahim Oğuz, İlbilge Oğuz, Osman Gökdoğan	Using of Digital Agriculture, Machine Learning, Remote Sensing and Smart Approaches in Fruit Orchards	Türkiye
	13	17:00	423	Melis Yağlı, Hasan Eleroğlu, Recep Gümüş	Teknolojik Gelişmelerin Kuluçka Makinesi Gelişimi Üzerine Etkisi	Türkiye

	14	17:20	505	Sevde Kara Yiğit, Katibe Sinem Coruk, Hande Baltacıoğlu, Cem Baltacıoğlu	Endüstri 4.0 Işığında Kurutma Teknolojilerinin Dijital Dönüşümü	Türkiye
	15	17:40	526	Burak Şen, Berna Gümüş	The Effects Of Deficit Irrigation On The Yield Parameters Of Some Strawberry Varieties In Nigde Conditions	Türkiye
	16	18:00	533	Zeynep Ünal	The Rise of Digital Agriculture and Sustainable Production with Smart Technologies	Türkiye
	17	18:20				

I. International Digital Agriculture Congress (INDAC)

18 September 2025

Niğde, Türkiye

Salon 1 / Hall 1

Moderator: Bilge Şevval Yıldırım and Musa Sürücü

Online Presentation

Link: [Genel | INDAC 2025 - Salon 1 / Hall 1 | Microsoft Teams]

Oturum Session	Sıra No	Saat Time	ID	Yazar Authors	Çalışmanın Adı Paper Name	Ülke Country
1	1	09:00	431	S.A.A.K. Abeywickrama , R.A.G.U. Ranasinghe	Food Safety Knowledge, Attitude, And Practices Among Employees : A Case Study At Food Court Of Kandy City Centre, Sri Lanka.	Sri Lanka
	2	09:20	432	B. Karmakar, A. Henry, S. Haefele, M. Mukul, M. Hasan, A. Kumar	Field Screening Of Rice Genotypes İn Drought-Prone Rainfed Environment	Bangladesh
	3	09:40	442	Sajid Al Azwad, Nazmul Hossain	Generatıon Of Vermıcompost From Invasıve Alıen Weed Mimosa Pudica By Employıng Eisenia Fetida: Nutrıent Content, Earthworm Fecundıty And Effects On Crop Growth Attrıbutes	Bangladesh
	4	10:00	482	Md. Abul Kashem, Khadeza Yasmin, Israt Jahan, Md. Imran Khan* and Saima Sadia Jui	Isolation, Characterization and Identification of Rhizobia From Root Nodules of French Bean (Phaseolus vulgaris L.) Grown in Acid Soils	Bangladesh
Mola / Break 10:20 – 10:40						

2	5	10:40	464	Hosameldeen Mohamed Husien, Mohamed Osman Abdalrahem Essa , Saber Y. Adam , Ahmed A. Saleh, Mengzhi Wang	Impact of Moringa oleifera Leaf Polysaccharide on Growth Performance, Serum Biochemical Indices and Immune Functions in Broiler Chickens	China
	6	11:00	492	Nada N. A. M. Hassanine , Ahmed A. Saleh,,*, Mayar Al-Mahrangi, Youssef Abdel-Gawad, Yara Abdel-Radi, Ahmed Zeytoun, Alaa Al-Masry, Osama Abdel-Gawad, Hosameldeen Mohamed Husien,,*, Mengzhi Wang,*	Designing And Creating A New Software Programme For Management İn Dairy Farms	China
	7	11:20	504	Sheham Guma İbrahim	Isolation And İdentification Of Citrobacter Freundii From Diseased Macrobrachium Nipponense	China
	8	11:40	519	R.A.G.U. Ranasinghe	Assessing The Labor Dynamics, Market Demand, And Strategic Challenges İn Domestic Tea Industry: (A Case Of Central Sri Lanka)	China
Mola / Break 12:00 – 13:20						
3	9	13:20	466	Mohamed Osman Abdalrahem Essa ,,, Liang Chen,Cheng Cheng , Layla Ahmed Mohammed Abdelhadi ,Saber Y. Adam , Hosameldeen Mohamed Husien, Ahmed A. Saleh ,, and Darong Cheng *	Oral Administration of Lactobacillus amylovorus Alleviates Diarrhea and Partially Restores Gut Microbiota in Neonatal Goats	China
	10	13:40	436	Vihi, S.K*., Abdullahi, S., Binuyo, G., Jesse, B And Owa, G.T	Use Of ICT And Social Media Platforms For Accessing Agricultural Information Among Poultry Farmers İn Jos South Local Government Area, Plateau State, Nigeria	Nigeria
	11	14:00		Optimizing the Effects of Additional Straw Returning on Soil Organic Carbon Components: Insights from a Chinese Long-Term Conservation Field	Francis Azumah Chimsah, Washidu Mohammed, Liqun Cai	China
	12	14:20	429	Merve Kahraman, Arif Topcu, A. Sami Koca	Seasonal Trends İn Adult Populations Of Mediterranean Fruit Fly, Ceratitis Capitata Wiedemann (Diptera:	Türkiye

					Tephritidae) İn Olive Groves Of Akhisar District İn Manisa, Türkiye	
Mola / Break 14:40 – 15:00						
4	13	15:00		Olumuyiwa Akin Olaniyi, Samson Abidoye, Micheal Dlamini	Perceptions and Effectiveness of Mobile Technology Among Extension Workers in Kwara State: Implications for Digital Extension Delivery in Nigeria.	Nigeria
	14	15:20	477	Helimi Samia-, Hamdi-Aissa Baelhadj, Koull Naima	Digital Soil Mapping Classes İn The Oued Righ Region Using A Random Forest Model (Southeastern Algeria)	Algeria
	15	15:40	445	Wadah ELSHEIKH*, İlknur UÇAK, M. Cüneyt BAĞDATLI	Migrations, Agricultural Production, and Food Crisis in the World	Sudan
	16	16:00	446	Wadah ELSHEIKH*, M. Cüneyt BAĞDATLI	Water Footprint in Food Production of Africa	Sudan
	17	16:20	448	Maliha AFREEN*, İlknur UÇAK, M. Cüneyt BAĞDATLI	The Causes and Effects of Climate Change on Decreasing Food Production in Africa	Pakistan
	18	16:40	449	Wadah ELSHEİKH*, M. Cüneyt BAĞDATLI , Muhammed Kamil ÖDEN	The Negative Effects of Global Warming on Water Resources and Agricultural Production in Darfur, Sudan	Sudan
	19	17:00	450	Oluwadare Adebisi , Yusuff Adebonuola Lawal , Samson Oladayo Ayanlade	Bridging the Energy Gap for Digital Agriculture: Challenges and Solutions for AI and Robotics Adoption in Sub-Saharan Africa's Smallholder Farms	Nigeria
	20	17:20	456	Özlem EROL, İlknur Uçak	Smart Livestock Applications	Türkiye
	21	17:40	513	Betül Demir, Abdurrahman Aksoy, Yeşim Dokuz, Burak Şen	Derin Öğrenme Tabanlı Bitki Hastalıkları Tespit ve Tahmin Sistemi: PlantVillage Veri Seti ile Uygulama	Türkiye
	22	18:00	434	Yosr Laayouni, Imen Tlili, Marwa Chouikhi, Hana Bouzahouane, Amina Ben Abdallah, Riadh Ilahy	Lycopene and total phenolic content in fresh and processed high-pigment and ordinary tomato fruits	Tunisia
	23	18:20	438	Khelladi Malika, Debab Abdelkader	Qualitative Management of Water Resources Through the Use of Treated Wastewater in Agriculture	Algeria
	24	18:40	447	Maliha AFREEN, İlknur UÇAK, M. Cüneyt BAĞDATLI	The Effect of Climate Change and Global Warming on Animal Welfare in Pakistan	Pakistan
	25	19:00	481	Elbar Djenette, Elbar Chaima Yasmine	Mechanisms of lead adsorption by organo-mineral composite in wastewater.	Algeria
	26	19:20	530	Aslı SÖZERİ, Saime ÜNVER İKİNCİKARAKAYA, Leyla İDİKUT, Kazım Emre GÖKTAŞ	Farklı Ön Uygulama Yapılan Kocadarı (Sorghum Vulgare L.) Tohumlarının Kontrollü koşullarda Çimlenme ve İlk Gelişme Dönemlerinin İncelenmesi	Türkiye

I. International Digital Agriculture Congress (INDAC)

18 September 2025

Niğde, Türkiye

Salon 2 / Hall 2

Moderator: Didem Karalar and M. Talha İnce

Online Presentation

Link: **Genel | INDAC 2025 - Salon 2 / Hall 2 | Microsoft Teams**

Oturum Session	Sıra No	Saat Time	ID	Yazar Authors	Çalışmanın Adı Paper Name	Ülke Country
1	1	09:00	461	Saber Y. Adam, , Mohammed H. Jammaa, , Mohammed Rashid AL Makhmari, Davies M. Pfukenyi, Mohamed Osman Abdalrahem Essa, Hosameldeen Mohamed Husien, , Abdallah A. Basher, Abdelkareem A. Ahmed*, Demin Cai*	Effects of traditional transportation on the behavior, welfare, and blood profile of local chicken: A case study in Sudan	Sudan
	2	09:20	510	Nurgül Arısoy, Zekeriya Can Erbil	AI-Assisted Generation of Datasets from Drone Imagery for Green Spaces	Türkiye
	3	09:40	509	Zekeriya Can Erbil, Ali Akçaova	Comparative Analysis of Traditional and AI-Assisted Visualization Techniques in Interior and Exterior Design	Türkiye
	4	10:00	486	Mukhayyokhon Saidova, Feruza Alimova, Surayyokhon Khasanova	Test Results of a Pneumatic Precision Seeder for Bare Cotton Seeds Under Climatic Conditions of Water-Eroded Soils	Uzbekistan

Mola / Break 10:20 – 10:40						
2	5	10:40	473	Maliha Afreen, İlknur Uçak	Evaluation Of Microbiological Quality Of Minced Beef Meat Coated With Chitosan Containing Garlic Esential Oil During Refrigerated Storage	Pakistan
	6	11:00		T. F. Ojo* and B. F. Balogun	Bridging the Digital Divide: An Assessment of Agricultural Extension Personnel's Usage of Digital Technology in Ondo State, Nigeria	Nigeria
	7	11:20	455	Özlem EROL, İlknur Uçak	Smart Packaging Technologies	Türkiye
	8	11:40	463	E. Mevliyaoğulları, S. Doğan, S. Göncü	Siyah Alaca Erkek ve Dişi Buzağılarda Doğum ve Sütten Kesim Dönemi Kan Değerleri Değişimi	Türkiye
Mola / Break 12:00 – 13:20						
3	9	13:20	467	Emmanuel Ugochukwu ANASO	Immune And Oxidative Stress Indices of Yankassa Rams Fed Diets Containing Urea-Molasses Treated Cassava Peel Ensiled with Caged-Layer Droppings	Nigeria
	10	13:40	515	Ömer Sefa Yüksel, Seda Şahin	Enhancing Smart Agriculture Through Multi-Stage Feature Selection And Iot-Driven Soil Intelligence	Türkiye
	11	14:00		Modeling the Process Of Interaction Of Loosening Organs With Soil	Feruza Alimova, Mukhayyokhon Saidova	
	12	14:20	468	Hatice Dilaver, Kamil Fatih Dilaver	Application of Artificial Intelligence Technologies in Livestock Management	Türkiye
Mola / Break 14:40 – 15:00						
4	13	15:00	435	Ahmet İlker MERMER*, Zafer DOĞU	Effects Of Sucrose And Some Cryoprotectants On DNA Damage And Fertilization Rates Of Frozen And Thawed Sperm Of The Mesopotamian Catfish (S.	Türkiye

	14	15:20				
	15	15:40		Beyza Yılmaz	Digital Welfare Approaches in Small Animals	Türkiye
	16	16:00	409	Femi Afolayan	Comparatıve Analysıs Of Growth Performance And Economıc Benefıts Of West Afrıcan Dwarf Goat Fed Wıth Dıets Incorporatıon Treated Rıce Husk As A Substıtute For Wheat Bran	Nigeria
	17	16:20		Chukwudi Ernest Ogbete, Miriam Ahunna Ofoeze	Harnessing Digital Agriculture for Food Science Innovation: A Review of Emerging Tools for Postharvest Quality, Safety, and Nutrition Enhancement	
	18	16:40	465	Peigeng Zhang	Biomechanical Risk Assessment of Watermelon Harvesting Using AI-Based Motion Analysis	USA
	19	17:00	531	Mutlu Bulut	Hayvancılık Sektöründe Dijital Tarımın Kullanım Alanları ve Ekonomik Katkıları	Türkiye
	20	17:20	537	Carlos Robles-Rojas	APP: Profitability Determination of Onion Cultivation	Costa Rica
	21	17:40	469	Ali Kaan Yetik	Optimizing Deficit Irrigation Strategies For White Cabbage Under Semi-Arid Conditions Using The Tagem-Suet Model	Türkiye
	22	18:00	430	Marwa Chouikhi, Riadh Ilahy, Imen Tlili, Thouraya R'him	Horticultural performance and functional quality traits of four hot pepper landraces from Tunisia	Tunisia
	23	18:20	500	Asiye ÇETİNKAYA, Fatma YENİLMEZ, Mikail BAYLAN	Tavukçulukta Ortaya Çıkan Altlıkların Yeniden Değerlendirilmesi: Çevresel ve Ekonomik Bir Yaklaşım	Türkiye
	24	18:40	501	Fatma YENİLMEZ	İklim Değişikliğinin Tavuklar Üzerindeki Etkisi	Türkiye

	25	19:00	516	CHAIB EDDOUR Ahmed Readh, LITIM Miloud, BOUDEROUA Kaddou	Dietary Dried Orange Pulp as a Functional Feed Ingredient to Improve Broiler Chicken Productivity	Algeria
	26	19:20	535	Aisha Idris Ali	Parkia biglobosa—a Tree of Food and Medicinal Values: Domesticate Them or Disappear	Nigeria
	27	19:40		Pesticide Residues in Date Palm and Olive Oil Samples Produced and Consumed in Jordan	Skandar Abo Gazlah, Ilahy Riadh, József Kiss	
	28	20:00				

I. International Digital Agriculture Congress (INDAC)

19 September 2025

Niğde, Türkiye

Salon 1 / Hall 1

Moderator: Nida Uysal, Ali Kaan Yetik

Online Presentation

Link: Genel | INDAC 2025 - Salon 1 / Hall 1 | Microsoft Teams

Oturum Session	Sıra No	Saat Time	ID	Yazar Authors	Çalışmanın Adı Paper Name	Ülke Country
1	1	09:00	483	Tayyaba Shaheen	In-silico identification of potential targets for Sugarcane Smut Disease	Pakistan
	2	09:20	444	M. Ersoy, K. Şengül, M. E. Topal, Z. Cebeci	Kümes İklimlendirmesinde Sensör Ağları ve Yapay Zeka Uygulamaları	Türkiye
	3	09:40	493	G. Tamer Kayaalp	The Estimation of Missing Data With Maximum Likelihood Methods In Animal Research	Türkiye
	4	10:00	494	G. Tamer Kayaalp*, Nazan Koluman	Comparison Of Different Lactation Curves Models İn Saanen Goats	Türkiye
Mola / Break 10:20 – 10:40						
2	5	10:40	460	Cevher Özden	Vision-Based Artificial Intelligence in Agriculture: Transformer-Based Plant Health and Disease Detection	Türkiye

	6	11:00	451	Yusuff Adebonuola Lawal, Oluwadare Adebisi, Shukurat Adedamola Wahab	The Role of Climate-Smart Agriculture (CSA) in Addressing the Challenges of Food Security and Climate Change in Sub-Saharan Africa: A Focus on Nigeria	Nigeria
	7	11:20	495	Elijah George Ikrang*, Akindele Folarin Alonge,Mfrekemfon Godswill Akpan	Effect Of Microwave Oven Drying On Some Nutritional And Anti-Nutritional Content Of Pretreated Paw-Paw (Carica Papaya) Pulp Using Response Surface Methodology	Nigeria
	8	11:40		Mahmood-ur-Rahman	Expression Analysis of Nickel Responsive Genes in Sunflower Under Stress Conditions	
Mola / Break 12:00 – 13:20						
3	9	13:20		Antibiotic Resistance of Some Enterobacteriaceae Strains Isolated from Bovine in The West of Algeria	Barka Mohammed Salih, Cherif-Anntar Asmaa	Algeria
3	10	13:40	441	Yusuff Adebonuola Lawal, Oluwadare Adebisi	Climate Change And Agricultural Sustainability İn Nigeria: Challenges And Policy Pathways, A Case Study Of Kishi, Oyo State.	Nigeria
3	11	14:00	520	Aidin Azizpour, Zahra Amirajam	Isolation And Antibiotic Resistance Profile Of Streptococcus Spp From Commercial Poultry Carcasses İn Ardabil Province, Northwest Of Iran	Iran
3	12	14:20	502	Ezgi DEMİR ÖZER	Integration Of Precision Agriculture Data For Quality And Traceability İn Food Production	Türkiye
Mola / Break 14:40 – 15:00						
4	13	15:00	503	Fatma Ebrar Öztürk, Hande Baltacıoğlu, ,*Cem Baltacıoğlu, ,Mehmet Yetişen, Hasan Uslu	Dijital Teknolojiler İle Entegre Edilmiş Akıllı Kurutma Sistemleri: Yeni Nesil Uygulamalar	Türkiye

	14	15:20		In vitro Antimicrobial and Antioxidant Activities of Cassia, Neem, and Fig Leaf Extracts Against Biofilm-Producing Staphylococcus aureus and Candida Species from Outpatients, Oyo Town, Nigeria	Racheal Oluwayemisi Fashogbon*, Oyindamola John Samson, Olusolabomi Jose Adefioye, Christiana Ure Mbabie, Odinakachi Mary Samuel, Ronke Mary Ojamami, Honey Temitope Ayeni, Gbemisola Ogunleye	Nigeria
	15	15:40		Khorsandi Kouhanestani, Zohreh	Investigating the Impact of Land Use Changes on Groundwater Quality in Arid and Semi-Arid Regions of Central Iran	Iran
	16	16:00		Elbar Djenette, Elbar Chaima Yasmine	Date and Lentil Powder: A Comprehensive Dietary Supplement	Algeria
	17	16:20	478	Bayyiğit, İ., Acıbuca, V.	Mardin İli Üzüm Üreticilerinin Tarımsal Bilinç Düzeyleri Ve Eğitim İhtiyaçlarının Belirlenmesi	Türkiye
	18	16:40	488	Madison Moore, Serap Gorucu, Nikolay Bliznyuk	Statistical Machine Learning Models for Agricultural Injury Surveillance Data	USA
	19	17:00	498	Farzaneh Khorsandi, Salah Issa, Serap Gorucu	Challenges and Safety Considerations in the Adoption of Autonomous Agricultural Vehicles	USA
	20	17:20	472	Serap Gorucu, Jacob Muller, Daniel Petti, Changying Li, Matthew Pilz, Bryan P. Weichelt	Evaluating Large Language Models For Agricultural Injury Surveillance	USA
	21	17:40	425	Ogunleye Gbemisola Elizabeth, Oyinlola Kubrat Abiola, Akintade Oluwarotimi Olutosin, Olatoye Motunrayo Janet, Oyelere Ayanfeoluwa, Fashogbon Racheal Oluwayemisi	Phyto-fabricated Selenium Nanoparticles from Corchorus olitorius leaf Extract: Antioxidant and Antibacterial properties	Nigeria
	22	18:00	536	Aisha Idris Ali	Bioactive Compounds and Bioactivities of Celtis zenkeri Leaves	Nigeria
	23	18:20	423	Melis Yağlı, Hasan Eleroğlu, Recep Gümüş	Teknolojik Gelişmelerin Kuluçka Makinesi Gelişimi Üzerine Etkisi	Türkiye
	24	18:40	518	CHAIB EDDOUR Ahmed Readh, LITIM Miloud, BOUDEROUA Kaddou	Toward Sustainable Poultry Nutrition: A Review of Agricultural By-Product and Waste Valorization	Algeria
	25	19:00	524	Gülden Sandal Erzurumlu	Ağaçların Mitolojisi: Kültürlerde Kutsal ve Sihirli Ağaçlar	Türkiye

	26	19:20		Femi Afolayan	Heamatology and Serum Biochemistry of West African Dwarf Goats Fed Diets Containing Treated Rice Husk (RH) as a Replacement for Wheat Bran	Nigeria
	27	19:40		Tefide Kızıldeniz*, Ebrar Kanyılmaz	The Potential of Microbial Fertilizers in Reducing Nutrient Losses in Hydroponic Systems	Türkiye

CONTENTS

Effects of Sucrose and some Cryoprotectants on Post-Thaw Sperm Quality (Spermatozoa Motility) and Fertilization of the Mesopotamian Catfish (*S. triostegus*, H. 1843)

Ahmet İlker Mermer[1], Zafer Doğu[2]

[1]Şanlıurfa Agriculture and Forestry Provincial Directorate, İmambakır M., 702nd S. No: 6, Haliliye/Şanlıurfa, TÜRKİYE
[2]Department of Aquaculture, Bozova Vocational School, Harran University, 63850, Bozova, Şanlıurfa, TÜRKİYE

Abstract

This study was conducted to investigate the effects of cryoprotectants such as sucrose and Dimethyl sulfoxide (DMSO), Methanol, and Methylglycol, along with a glucose diluent, on the post-thaw spermatozoa motility and fertilization of *Silurus triostegus* larvae in the Atatürk Dam Lake. The 4-5 year old *S. triostegus* used in the study were caught from the Atatürk Dam Lake in Şanlıurfa province. Post mortem, the examinations of sperm samples taken from *S. triostegus* through abdominal massage were conducted in the laboratories of the Fisheries Department at Harran University Bozova Vocational School. After the examination, those with 80% and above motility and spermatozoa density of 9.00-14.00 X 10^9/ml were selected. Sperms were diluted at a ratio of 1/3 with a glucose sperm diluent containing 5% Dimethyl sulfoxide (DMSO), Methanol, or Methylglycol as one of the cryoprotectants, and 50 mM sucrose, 20% egg yolk, and 0.3 M glucose at 4 ºC. The control group sperm diluent used was a glucose sperm diluent containing 10% DMSO, Methanol, or Methylglycol, 50 mM sucrose, 20% egg yolk, and 0.3 M glucose. After the sperm was diluted, it was subjected to equilibration at 4 °C for 10 minutes. After being frozen in liquid nitrogen vapor for 12 minutes, it was stored in liquid nitrogen (-196 °C). After thawing, the spermatozoa motility rate was highest in the DMSO group at 30.00±3.51% ($P<0.05$). The highest fertilization rate was also found in the DMSO+Sucrose group (20.33±1.52) ($P<0.05$). In the sucrose control group, fertilized eggs (% 0.0±0.00) could not be detected. The study findings indicate that the glucose sperm diluent containing 5% DMSO and 50 mM sucrose is suitable for spermatozoa motility and fertility in *S. triostegus* after dissolution.

Key Words: *Silurus triostegus, Sperm, Freezing, Sucrose, Cryoprotectant*

*: This study is a part of the master's thesis titled " **Effects of Sucrose Added to Diluent In Cryopreservation of Mesopotamian Catfish (*S. triostegus*, H. 1843) Semen Quality After Thawing** " by the first author.

Optimizing the Effects of Additional Straw Returning on Soil Organic Carbon Components: Insights from a Chinese Long-Term Conservation Field Study

Francis Azumah Chimsah[1], Washidu Mohammed, Liqun Cai[2]

[1]Department of Horticulture, Faculty of Agriculture, University for Development Studies, Tamale, Ghana
[2]College of Resources and Environmental Sciences, Gansu Agricultural University, Lanzhou, China

Abstract

Since the return to straw management in conservation fields, it remains unknown the optimum quantity needed for good soil health and plant production. This study aims at highlighting the lessons from a study conducted on an existing long term-term conservation tillage field within the Gansu Province of China. Two main tillage types, conventional tillage with straw returns (TS) and no tillage with straw returns (NTS) with four different additional straw return treatment levels of spring wheat and field pea as test crops. NTS fields showed more sensitivity to treatment effect. NTS fields had significantly higher grain yield. NTS fields had significantly higher SOC content than TS fields with SOC ranging from 5.56 – 20.77 g kg-1. No straw addition (NSA 0x) and low straw addition (LSA 1x) levels recorded higher yields in wheat fields whiles for pea fields, it was LSA 1x and medium straw addition (MSA 2x). The observed trend in terms of increasing SOC content among the straw addition treatments was LSA 1x > NSA 0x > MSA 2x > high straw addition (HSA 3x). Highest accumulated SOC stocks was observed under LSA 1x while lowest SOC stocks was NSA 0x. The relative intensities of the C-H bonds were higher in LSA 1x and also, was more effective in increasing soil hydrophobicity. Straw addition to conservation fields has limit and lessons leant from this study can serve as guide to better understanding the complexities of our farming systems in our quest for sustainable agriculture production.

Key Words:

Comparative Analysis of Growth Performance and Economic Benefits of West African Dwarf Goat Fed With Diets Incorporation Treated Rice Husk as a Substitute for Wheat Bran

Femi Afolayan[1]

[1]Department of Agricultural Science Education, School of Vocational and Technical Education, Kwara State College of Education, Oro, Nigeria

Abstract

The study was conducted to find out effects of treated rice husk as a replacement for wheat bran supplement on the growth performance of West African Dwarf (WAD) goats. Twenty (20) WAD goats were subjected to five dietary treatments in a Completely Randomized Design (CRD) with four (4) animals per treatment and each serving as a replicate. The treatments are: 0% RH (T1), 25% RH (T2), 50% RH (T3), 75% RH (T4) and 100% RH (T5). The animals were fed 5% of their body weight. The result showed that T2 and T1 are relatively high in crude protein, low in crude fiber, moderate in crude fat and high in carbohydrate. They equally had the lowest values of ADF, ADL and NDF among the treatments. The total weight gain (TWG), average daily weight gain (ADWG), total daily feed intake (TDFI) and feed conversion ratio (FCR) were all significantly ($P < 0.05$) influenced by the dietary treatments. The goat, T1 had the highest TWG, ADWG and TDFI values among the goats. The goat fed 25% RH replacement level (T2) converted and utilized feed better and had better growth performance comparable to goats fed T1. In conclusion, at 25% level of treated rice husk as replacement of wheat bran gave better growth performance in the goats. The result demonstrated the qualitative benefits and financial returns of using treated rice husk to replace wheat bran diets for WAD goats. Thus, the use of treated rice husk up to 50% in the diet of WAD goats is recommended for appreciable growth performance and better economic benefits.

Key Words: *Treated rice husk, West African Dwarf goat, Weigh gain, Feed conversion ratio, Feed intake*

Heamatology and Serum Biochemistry of West African Dwarf Goats Fed Diets Containing Treated Rice Husk (RH) as a Replacement for Wheat Bran

Femi Afolayan[1]

[1]Department of Agricultural Science Education, School of Vocational and Technical Education, Kwara State College of Education, Oro, Nigeria

Abstract

The study was conducted to evaluate the effects of treated rice husk as a replacement for wheat bran on the haematology and serum biochemical parameters of West African Dwarf (WAD) goats. Twenty WAD goats were subjected to five dietary treatments in a completely randomized design with four goats per treatment. The treatments were 0% RH (T1), 25% RH (T2),50% RH (T3),75% RH (T4) and 100% RH (T5). The animals were fed at 5% of their body weight. Blood samples of 10 ml were collected at the end of the growth trial to analyze for haematology and biochemical components. Blood samples were taken before morning feeding via jugular vein puncture into two blood collection bottles. One containing an anticoagulant Disodium salt of ethylene diamine tetraacetic acid (EDTA) and the other with no anticoagulant from which serum was harvested for biochemical analysis. Packed Cell Volume (PCV), Haemoglobin (Hb), red blood cell (RBC) and total white Blood Cells (WBC) were determined. Mean Corpuscular volume (MCV), Mean Corpuscular haemoglobin (MCH) and Mean Corpuscular haemoglobin concentration (MCHC) was calculated from PCV, Hb and RBC. Serum biochemical parameters measured include glucose, total protein, albumin, blood urea nitrogen (BUN), aspartate aminotransferase (AST) and alanine aminotransferase (ALT) parameters were determined. Goat fed with diet T4 had better red blood cell, Pcv, hemoglobin, platelet, eosinophil and AST but high in cholesterol level. Goat on T2 had the highest Tp and better hemoglobin, Pcv, platelet lymphocytes, ALT and globulin content. The treated rice husk had positive impact on the blood parameters, the values are within the normal range for healthy goat. Hence, from this study, 25 – 50% treated rice husk replacement for wheat bran suggests suitable for better performance of WAD goats.

Key Words:

Electrocoagulation Applications in Microplastic Removal from Sediment Environment

Şule Sancak[1]

[1]Department of Environmental Engineering, Faculty of Engineering, Ondokuz Mayıs University, Samsun, Turkey

Abstract

It is known that one of the important sources of water pollution is plastic pollution. Plastics left in natural environments are exposed to various physical and chemical decomposition processes and turn into microplastics. Microplastics, which tend to accumulate in the bodies of living beings, especially in the aquatic ecosystem, can pose a danger to the environment and life in the long term. In order to remove microplastics from the aquatic ecosystem, the sediment layer at the bottom of the water should also be evaluated. Microplastic pollution can only be efficiently eliminated by considering the water and sediment environment in an integrated manner. Microplastic removal studies, which have accelerated in recent years, offer many different removal methods. The advantages it provides in removing microplastics from the water environment in particular have made the electrocoagulation method remarkable. However, there is no application of the electrocoagulation method for the sediment environment. This study includes electrocoagulation applications in the laboratory for the removal of microplastics from the sediment environment. pH, % water content, % organic matter content analyses were primarily performed on sediment samples taken from Samsun Kızılırmak in two seasons. Then, electrocoagulation was applied to the sediment samples using an electrocoagulation process consisting of a unit, power supply and conductive plates. Different operating conditions were determined for each sample. Thus, it was aimed to evaluate the optimum operating conditions. Before and after the electrocoagulation application, interface water was taken from the sediment samples and filtered by vacuum filtration. In the final stage, the filters were dried in the oven and made ready for FTIR analysis. When the FTIR analysis results before and after the electrocoagulation process were examined, it was seen that 96% and 99% removal was achieved for both samples, respectively. The results show that microplastics were successfully removed from the sediment samples in the laboratory environment with this method. Analyses are ongoing to develop this study, which is a guide for subsequent studies.

Key Words: *Plastic pollution, Microplastic, Sediment, Electrocoagulation, Water pollution*

Sediman Ortamından Mikroplastik Gideriminde Elektrokoagülasyon Uygulamaları

Özet

Su kirliliğinin önemli kaynaklarından birinin plastik kirliliği olduğu bilinmektedir. Doğal ortamlara bırakılan plastikler çeşitli fiziksel ve kimyasal ayrışma süreçlerine maruz kalarak mikroplastiklere dönüşürler. Özellikle su ekosistemindeki canlıların bünyelerinde birikme eğilimi gösteren mikroplastikler, uzun vadede çevre ve canlı yaşamı için tehlike oluşturabilir. Mikroplastiklerin su ekosisteminden uzaklaştırılması için su tabanında yer alan sediman tabakasının da değerlendirilmesi gerekir. Mikroplastik kirliliği ancak su ve sediman ortamının entegre olarak ele alınması ile verimli bir şekilde ortadan kaldırılabilir. Son yıllarda hızlanan mikroplastik giderim çalışmaları birçok farklı giderim yöntemi sunmaktadır. Özellikle su ortamından mikroplastiklerin uzaklaştırılmasında sağladığı avantajlar, elektrokoagülasyon yöntemini dikkat çekici hale getirmiştir. Ancak sediman ortamı için elektrokoagülasyon yönteminin herhangi bir uygulaması bulunmamaktadır. Bu çalışma sediman ortamından mikroplastiklerin giderimi için laboratuvarda elektrokoagülasyon uygulamalarını içermektedir. Samsun Kızılırmak'tan iki mevsim olarak alınan sediman örneklerine öncelikli olarak pH, %su içeriği, %organik madde içeriği analizleri yapılmıştır. Ardından bir ünite, güç kaynağı ve iletken plakalardan oluşan elektrokoagülasyon prosesi kullanılarak sediman örneklerine elektrokoagülasyon uygulanmıştır. Her bir örnek için farklı çalışma koşulları belirlenmiştir. Böylece optimum çalışma koşullarının değerlendirilmesi hedeflenmiştir. Elektrokoagülasyon uygulamasından önce ve sonra sediman örneklerinden arayüz suyu alınmış ve vakum filtrasyonu ile filtre edilmiştir. Son aşamada filtreler etüvde kurutulmuş ve FTIR analizine hazır hale getirilmiştir. Elektrokoagülasyon işleminden önce ve sonraki FTIR analiz sonuçları incelendiğinde her iki örnek için sırasıyla %96 ve %99 giderim sağlandığı görülmektedir. Sonuçlar, bu yöntem ile laboratuvar ortamında mikroplastiklerin sediman örneklerinden başarıyla uzaklaştırıldığını göstermektedir. Sonraki çalışmalar için yol gösterici nitelikte olan bu çalışmanın geliştirilmesi için analizler sürmektedir.

Anahtar Kelimeler: *Plastik kirliliği, Mikroplastik, Sediman, Elektrokoagülasyon, Su kirliliği*

Phyto-Fabricated Selenium Nanoparticles from *Corchorus Olitorius* Leaf Extract: Antioxidant and Antibacterial Properties

Ogunleye Gbemisola Elizabeth[1*], Oyinlola Kubrat Abiola[2], Akintade Oluwarotimi Olutosin[3], Olatoye Motunrayo Janet[1], Oyelere Ayanfeoluwa[1] Fashogbon Racheal Oluwayemisi[4]

[1]Department of Biological Sciences, KolaDaisi University, Ibadan, Nigeria
[2]Department of Microbiology, University of Ibadan, Nigeria
[3]Department of Chemical Sciences, KolaDaisi University, Ibadan, Nigeria
[4]Department of Microbiology, Ajayi Crowther University, Nigeria
*Corresponding author: geegbemz@gmail.com

Abstract

Corchorus olitorius is a vegetable that is highly medicinal, rich in antioxidant properties and can be used for the synthesis of nanoparticles. Selenium is essential in the diet of humans, mammals and every other forms of life. This study is aimed at investigating the potential of *C. olitorius* for the synthesis of selenium nanoparticles (SeNPs) and their antioxidant and antibacterial activities. Selenium nanoparticles was phytosynthesized using *C. olitorius* leaf extract and characterized using UV-Visible spectroscopy, Scanning Electron Microscope, Transmission Electron Microscope, X-ray diffraction (XRD), Energy dispersive X-ray (EDX) and Fourier Transform Infra-red spectroscopy. Antioxidant activity of synthesized Selenium nanoparticles was done using (DPPH). Agar well diffusion method was used for the antimicrobial assay. Synthesis of SeNPs using *C. olitorius* (CO-SeNPs) was characterized by a strong plasmon resonance peak at 350 nm and had a broad band between 250 - 450 nm. The CO-SeNPs were spherical in shape with uniform sizes ranging from 50 – 100 nm. EDX analysis shows that selenium has the strongest signal and potassium was the weakest. Sharp peaks were observed in the XRD analysis indicating the formation of crystalline SeNPs. Hydroxyl, amine, thiol, and alkene were present which may be responsible for the efficient stabilization and bioreduction of SeNPs. The CO-SeNPs exhibited potent antioxidant activity ranging from 20.28% at 50ug/ml to 66.53% at 250ug/ml. Antimicrobial activity of CO-SeNPs ranged from 14±0.45 - 23±0.56 mm. Pyhto- synthesis of selenium nanoparticles from *C. olitorius* is a promising method in the biomedical field, due to its high bioactive components.

Key Words: *Medicinal plant**,** Selenium nanoparticles, Corchorus olitorius, Antioxidant activities, Phytosynthesis*

In vitro Antimicrobial and Antioxidant Activities of Cassia, Neem, and Fig Leaf Extracts Against Biofilm-Producing *Staphylococcus aureus* and *Candida* Species from Outpatients, Oyo Town, Nigeria

Racheal Oluwayemisi Fashogbon[1*], Oyindamola John Samson[1], Olusolabomi Jose Adefioye[1], Christiana Ure Mbabie[1], Odinakachi Mary Samuel[1], Ronke Mary Ojamami[1], Honey Temitope Ayeni[1], Gbemisola Ogunleye[2]

[1]Department of Microbiology and Biotechnology, Faculty of Natural Sciences, Ajayi Crowther University, Oyo State, Nigeria
[2]Department of Microbiology, Faculty of Natural Sciences, Kings University, Osun State, Nigeria
[3] Department of Biological Sciences, Faculty of Natural Sciences, KolaDaisi University, Oyo State, Nigeria
*Corresponding Author: ro.fashogbon@acu.edu.ng

Abstract

Biofilm-related infections are difficult to treat due to limited effective management options, posing a significant clinical problem. Eradicating biofilm with antibiotics alone is challenging, highlighting the need for alternative treatments, such as plant extracts. This study aims to evaluate the antimicrobial and antioxidant potential of leaf extracts from Cassia, Neem, and Fig against biofilm-producing strains of *Candida* spp. and *Staphylococcus* aureus isolated from outpatients with high vaginal swabs (HVS) in Oyo Town, Southwest Nigeria. Isolation of *Candida* spp. and *Staphylococcus aureus* was done on Saboraud Dextrose Agar and Mannitol Salt Agar respectively. *Candida* spp. were identified and characterized using Chrom agar, germ-tube test, and Gram staining while biochemical and coagulase test was used to identify *Staphylococcus aureus*. Biofilm (tube test and Congo red agar) and antimicrobial assay using agar well diffusion was done on the isolates. Thirty-six (36) *Candida* spp. (55.56% *C. albicans*, 21.67% *C. krusei,* and 2.27% *C. glabrata*) and thirty-five (35) Gram-positive bacteria (45% *S. aureus,* 58.3% *S. epidermidis* and 43.1% *Streptococcus* spp.) were isolated. Thirty-one (86.11%) *Candida* spp. and twenty-six (74.29%) *S. aureus* isolates were positive for both Congo red and test tube tests. Ethanol extract of Cassia had the highest antimicrobial activity against *Staphylococcus aureus* while *Candida* spp. were only sensitive to ethanol extracts of the three plants. This study recommends that further studies should be carried out to discover the active components of Cassia, Neem, and Fig which can be harnessed for their potential to successfully treat infections caused by biofilm-forming organisms.

Key Words: *High vaginal swab, Test tube test, Antimicrobial assay, Plant extracts, Biofilm formation*

Antibiotic Resistance of Some *Enterobacteriaceae* Strains Isolated from Bovine in The West of Algeria

Barka Mohammed Salih[1], Cherif-Anntar Asmaa[1]

[1] Dept. of Science, Institute of Science and Applied Technology University of Tlemcen , Algeria

Abstract

The misuse of antibiotics in cattle breeding is a phenomenon that still exists on some farms in the northwest of Algeria. This calls into question the effectiveness of available treatments and threatens human and animal health. The aim of this study is to try to determine the antimicrobial resistance (AMR) patterns of some *Enterobacteriaceae* to antibiotics in healthy cattle. Samples from bovine were taken using sterile swabs on the skin of cattle and different places in the stable and prepared for culture using conventional microbiological techniques. Isolates were identified biochemically using API 20E. In accordance with nccls guidelines, all isolates were identified and analyzed using the Kirby Bauer disk diffusion technique against 20 antibiotic disks. A total of 356 distinct species of *E. coli* were isolated. Twenty two agglutinable *E. coli* isolates with O157 :H7 were found using serotyping. *E. Coli* resistance to nalidixic acid (85.7%), tetracyclin (68.2%), streptomycin (53.5%), nitrofurantoin (75.4%), ampicillin (48.6%), ticarcillin (37.4%), piperacillin (41.8%), and chloramphenicol (19.2%) was highly prevalent when it came to antibiotic susceptibility. Some Serratia species present a resistance of 55.9% to nalidixic acid and ofloxacin, 52.3% to ciprofloxacin and 29.54% to streptomycin. Enterobacter isolated were resistant to ampicillin, and cefazolin, however no resistance was observed for gentamicin, amikacin and kanamycin.The Klebsiella species shows no resistance for gentamicin, amikacin and kanamycin, but 69% ciprofloxacin 42% ofloxacin, and a total resistance to tetracyclin and ampicillin. Resistance to more than four antibiotic classes, was present in 75.6% of the isolates. The PCR technique showed that all the twenty two *E.coli* O157 :H7 carried the *stx2* and the *ehxA* genes, 5 isolate carried *stx1* genes and 3 both *stx1* and *stx*2.

Key Words: *Bovine, Enterobacteriaceae, Multidrug resistance, E.coli O157 :H7.*

Seasonal Trends in Adult Populations of Mediterranean Fruit Fly, *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) in Olive Groves of Akhisar District in Manisa, Türkiye

Merve Kahraman1, Arif Topcu1, A. Sami Koca2

[1] Bolu Abant İzzet Baysal University, Institute of Postgraduate Education, Bolu, Türkiye
[2] Bolu Abant İzzet Baysal University, Faculty of Agriculture, Department of Plant Protection, Bolu, Türkiye

Abstract

The Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), is a highly destructive pest that poses a major threat to many cultivated crops globally. It causes significant economic losses by infesting a wide range of fruits, including olives, which play a critical importance in agricultural production in Türkiye. In 2023, Manisa province ranked first in table olive production, fifth in oil olive production, and second in total olive production. The present study aimed to monitor the seasonal population dynamics of *C. capitata* adults in olive groves located in Akhisar district, Manisa, Türkiye, during the 2024 season. The research was conducted in two olive orchards (Çamönü and Efendi/Akhisar location) using McPhail traps baited with 2% diammonium phosphate (DAP) as the attractant. Three traps were placed in each orchard, and weekly sampling was carried out from June to November. The first adult flies were captured on 31 August in the Efendi location, averaging 2 adults per trap. The population peaked on 28 September with 112.3 flies per trap in the Efendi location. In the Çamönü location, adults were first recorded on 13 September with 1 adult per trap. The peak population in Çamönü occurred on October 26, reaching an average of 84.6 flies per trap. These observations contribute to a better understanding of the population dynamics of C. capitata and may assist in refining pest management approaches in the region.

Key Words: *Ceratitis capitata, Olive, Population dynamics, Akhisar, Manisa*

Manisa İli Akhisar İlçesi Zeytinliklerinde Akdeniz Meyve Sineği *Ceratitis Capitata* Wiedemann (Diptera: Tephritidae)'nın Ergin Popülasyonlarının Mevsimsel Eğilimleri

Özet

Akdeniz meyve sineği, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), dünya genelinde birçok kültür bitkisi için büyük bir tehdit oluşturan önemli bir zararlıdır. Türkiye'de tarımsal üretimde kritik öneme sahip zeytin başta olmak üzere çok çeşitli meyvelerde zarar oluşturarak önemli ekonomik kayıplara neden olmaktadır. 2023 yılında Manisa ili sofralık zeytin üretiminde birinci, yağlık zeytin üretiminde beşinci, toplam zeytin üretiminde ise ikinci sırada yer almıştır. Bu çalışma, 2024 üretim sezonunda Manisa ilinin Akhisar ilçesindeki zeytinliklerde *C. capitata* ergin bireylerinin mevsimsel popülasyon dinamiklerini izlemeyi amaçlamaktadır. Araştırma, Çamönü ve Efendi lokasyonlarında yer alan iki zeytin bahçesinde gerçekleştirilmiş olup, cezbedici olarak %2 diamonyum fosfat (DAP) içeren McPhail tuzakları kullanılmıştır. Her bahçeye üçer adet tuzak yerleştirilmiş ve Haziran-Kasım ayları arasında haftalık örneklemeler yapılmıştır. Efendi bölgesinde ilk ergin bireyler 31 Ağustos tarihinde yakalanmış olup, ortalama tuzak başına 2 birey tespit edilmiştir. Popülasyon yoğunluğu 28 Eylül'de en yüksek seviyeye ulaşarak tuzak başına ortalama 112,3 birey olarak kaydedilmiştir. Çamönü bölgesinde ilk ergin bireyler 13 Eylül'de yakalanmış ve tuzak başına ortalama 1 birey tespit edilmiştir. Bu lokasyonda popülasyonun en yüksek seviyeye ulaştığı tarih 26 Ekim olup, tuzak başına ortalama 84,6 birey kaydedilmiştir. Bu gözlemler, C. capitata'nın popülasyon dinamiklerinin daha iyi anlaşılmasına katkıda bulunmakta ve bölgede zararlı yönetimi yaklaşımlarının geliştirilmesine yardımcı olabilecek veriler sağlamaktadır.

Anahtar Kelimeler: *Ceratitis capitata, Zeytin, Popülasyon dinamiği, Akhisar, Manisa*

Bridging the Digital Divide: An Assessment of Agricultural Extension Personnel's Usage of Digital Technology in Ondo State, Nigeria

T. F. Ojo[1*] and B. F. Balogun[1],

[1]Department of Agricultural Extension and Rural Development, Faculty of Agriculture
Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria
Email: tfojo@oauife.edu.ng
Email: folayemibukola2@gmail.com

Abstract

This study assessed the utilization of digital technologies by public agricultural extension agents in Ondo State, Nigeria, for disseminating agricultural information. Data were collected from all (60) the extension personnel working with Ondo State Agricultural Development Programme using a structured questionnaire. Data analysis was carried out using descriptive statistics (frequency distributions, means, percentages) and inferential statistics (Chi-square tests, Pearson Product Moment Correlation) to test the study's hypotheses. The results revealed that mobile phone (100%), social media platform (98.3%), e-mail and SMS messaging tools (98.3%) were most available digital tools. Social media platform ($\bar{x}$ = 6.97) and television and radio broadcast ($\bar{x}$ = 6.97) were mostly utilised digital tools by the extension personnel for extension service delivery. The majority (66.7%) of the respondents had high knowledge in the use of digital technology for their extension work. Unstable power supply ($\bar{x}$ =1.98, high cost of Information Technology gadgets ($\bar{x}$ =1.83) and inadequate income to undertake digital technology training ($\bar{x}$ =1.78) were major constraints to the utilization of digital technology. Also, significant relationship existed between respondents' knowledge of digital technology (r=0.660) and the usage of digital technology (r=0.660). The study concluded that majority of the extension personnel utilised digital tools at high level for documentation, dissemination and information gathering purposes. To enhance the effectiveness of digital technology in agricultural extension services, it is recommended to stabilize power supply and provide continuous training to improve digital literacy among extension agents.

Key Words: *Digital technology, Agricultural extension, Information dissemination, Extension personnel*

Effects of Sucrose and Some Cryoprotectants on DNA Damage and Fertilization Rates of Frozen and Thawed Sperm of The Mesopotamian Catfish (*S. Triostegus*, H. 1843)

Ahmet Ilker Mermer[1]*, Zafer Doğu[2]

[1]Şanlıurfa Agriculture and Forestry Provincial Directorate, İmambakır M., 702nd S. No: 6, Haliliye/Şanlıurfa, TÜRKİYE
[2]Department of Aquaculture, Bozova Vocational School, Harran University, 63850, Bozova, Şanlıurfa, TÜRKİYE

Abstract

This study was conducted to investigate the effects of cryoprotectants containing sucrose and Dimethyl sulfoxide (DMSO), Methanol, and Methylglycol on the post-thaw DNA damage and fertilization of *Silurus triostegus* larvae sperm from the Atatürk Dam Lake.The study was conducted on *S. triostegus* (4-5 years old) caught from the Atatürk Dam Lake in Şanlıurfa province. Sperm was collected from freshly caught *S. triostegus* through abdominal massage. Sperm examinations were carried out in the laboratories of the Fisheries Department at Harran University Bozova Vocational School. After the examination, sperm with a motility of 80% and above and a spermatozoa density between 9.00-14.00 X 10^9/ml were selected. Spermatozoa were diluted at a ratio of 1/3 with a glucose sperm diluent containing 5% Dimethyl sulfoxide (DMSO), Methanol, or Methylglycol as one of the cryoprotectants, and 50 mM sucrose, 20% egg yolk, and 0.3 M glucose at 4 ºC. The control group sperm diluent used was a glucose sperm diluent containing 10% DMSO, Methanol, or Methylglycol, 50 mM sucrose, 20% egg yolk, and 0.3 M glucose. After the sperm was diluted, it was subjected to equilibration at 4°C for 10 minutes. After being frozen in liquid nitrogen vapor for 12 minutes, it was stored in liquid nitrogen (-196 °C). Post-thaw spermatozoon DNA damage Intracellular 8-OHdOG was determined using the ELISA and comet assay methods. After the examination of 8-Hydroxydeoxyguanosine (8-OHdG), the Methanol+Sucrose group showed the highest DNA damage with 123.86±4.08 ng/ml ($P<0.05$), while the DMSO+Sucrose group showed similarity with these control groups. In the Comet Assay Method, the DMSO+Sucrose experimental group exhibited significantly lower DNA damage, whereas the Methanol+Sucrose group was found to have high DNA damage ($P<0.05$). Additionally, the highest fertilization rate was observed in the DMSO+Sucrose group (20.33±1.52%) ($P<0.05$), while no fertilized eggs (0.0±0.00%) were detected in the sucrose control group.The study findings have shown that the glucose sperm diluent containing 5% DMSO and 50 mM sucrose is suitable for *S. triostegus* due to its low DNA damage and high post-thaw fertility.

Key Words: *Silurus triostegus, Sperm, Freezing, Sucrose, DNA damage*

:* This study is a part of the master's thesis titled "Effects of Sucrose Added to Diluent In Cryopreservation of Mesopotamian Catfish (*S. triostegus*, H. 1843) Semen Quality After Thawing**" by the first author.

Sukroz ve Bazı Kryoprotektanlar ile Dondurulan Mezopotamya Yayın Balığı (*S. triostegus*, H. 1843) Spermasının Çözüm Sonrası DNA Hasarı ve Fertilizasyon Oranları Üzerine Etkileri

Ahmet Ilker Mermer[1]*, Zafer Doğu[2]

Özet

Bu çalışma Atatürk Baraj Gölü'ndeki *Silurus triostegus* ların spermalarının sukroz ve Dimethyl sulfoxide (DMSO), Methanol ve Metilglikol gibi kriyoprotektan içeren glukoz sulandırıcısı dondurmanın çözüm sonrası DNA hasarı ve fertilizasyona etkilerini araştırmak amacıyla yapıldı. Çalışma, Şanlıurfa ili Atatürk Baraj Gölü'nden yakalanan *S. triostegus* (4-5 yaşlarındaki) larda yapılmıştır. Yeni yakalanmış, *S. triostegus*'tan abdominal masajla sperma alındı. Harran Üniversitesi Bozova Meslek Yüksekokulu, Su Ürünleri Bölümü laboratuarlarında sperma muayeneleri yapıldı. Muayene sonrası % 80 ve üzeri motilitede, Spermatozoa yoğunluğu 9,00-14,00 X 10^9/ml arası spermalar seçildi. Spermalar, % 5 oranındaki Dimethyl sulfoxide (DMSO), Methanol ve Metilglikol gibi kriyoprotektanlardan birisi ve 50 mM sükroz, % 20 yumurta sarısı ve 0,3 M glukoz içeren glukoz sperma sulandırıcısı ile 4 ºC'de 1/3 oranında sulandırıldı. Kontrol grubu sperma sulandırıcısı ise % 10 oranında DMSO, Metanol, Metilglikolden birisi, 50 mM sükroz, % 20 yumurta sarısı ve 0,3 M glukoz içeren glukoz sperma sulandırıcısı kullanıldı. Sperma sulandırıldıktan sonra 4°C 10 dakika ekilibrasyona tabi tutuldu. Sıvı azot buharında 12 dakikada dondurulduktan sonra, sıvı azot içinde (-196 °C'de) muhafaza edildi. Çözüm sonrası spermatozoon DNA hasarı Hücre içi 8-OHdOG ELISA ve comet assay yöntemi ile belirlendi. 8-Hidroksideoksiguanozin (8-OHdG) incelenmesi sonrasında Methanol+Sükroz grubu 123.86±4.08 ng/ml ile en yüksek DNA hasarı gösterirken (P<0,05), DMSO+Sükroz grubu bu kontrol gruplarıyla benzerlik gösterdi. Comet Assay Yönteminde, DMSO+Sükroz deneme grubu, önemli düzeyde düşük DNA hasarına sahipken, aksine Methanol+Sükroz grubu yüksek olduğu belirlendi (P<0,05). Ek olarak, en yüksek fertilizasyon oranı DMSO+Sükroz grubunda (%20,33±1,52) de tespit edilirken (P<0,05), sükroz kontrol grubunda fertil yumurta (% 0,0±0,00) belirlenemedi. Çalışma bulguları % 5 DMSO ve 50 mM sükroz içeren glukoz sperma sulandırıcısının DNA hasarının azlığı ve çözüm sonrası fertilitenin yüksek olması nedeniyle *S. triostegus* için uygun olduğunu göstermiştir.

Anahtar Kelimeler: *Silurus triostegus, Sperm, Kriyoprezervasyon, Sukroz, DNA hasarı*

*: Bu çalışma birinci yazarın "**Mezopotamya yayın balığı (*Silurus triostegus*, H. 1843) spermasının dondurulmasında sulandırıcıya katılan sükrozun çözüm sonrası sperma kalitesine etkileri"** adlı yüksek lisans tezinin bir bölümüdür**.**

Digital Welfare Approaches in Small Animals

Beyza Yılmaz[1]

[1]Department of Animal Production and Technology, Faculty of Agricultural Sciences and Technologies, Nigde Ömer Halisdemir University, Nigde, Türkiye

Abstract

Today, the technological requirements for individual, continuous and objective monitoring of small ruminant health can be met with digital agricultural systems and artificial intelligence-supported data processing techniques. Monitoring welfare indicators in animal husbandry is of strategic importance not only in terms of animal health, but also in terms of public health, control of antibiotic use and production efficiency. Recent studies have shown that wearable non-invasive biosensors can monitor physiological and behavioral parameters such as body temperature, heart rate, movement level, environmental stress factors and location information in small ruminants with high accuracy. The transfer of multiple data streams obtained from these sensors to cloud-based platforms via wireless communication systems has made real-time analysis possible. When this technological infrastructure is integrated with machine learning algorithms, it paves the way for innovative analysis forms such as health risk scores and individual welfare assessment specific to each animal. In this way, early-stage diagnosis of diseases, prediction of periods close to birth and detection of behavioral anomalies become possible. Similarly, Brucella spp. and early symptoms of zoonotic agents such as Coxiella burnetii, such as fever, lethargy and isolation behaviors, can also be reliably distinguished with artificial intelligence-supported systems. In systems developed specifically for small ruminants, it is of great importance that sensor configurations are ergonomic, modular and low-cost. Designs compatible with different carrier forms such as ear tags, chest bands or back belts allow data collection without disrupting the animal's natural behavior and increase comfort for the user and the animal in long-term field applications. Such biosensor and artificial intelligence-integrated solutions will offer the most concrete outputs of digitalization in animal husbandry in terms of improving animal welfare, reducing antibiotic use, providing labor support to the producer and developing early warning systems against zoonotic diseases. In this context; advanced sensor integration, optimization of machine learning models and the joint evaluation of cloud-supported mobile notification systems are among the critical elements for the success of digital welfare monitoring systems.
Key Words: *Biosensor, Artificial intelligence, Animal welfare, Digital agriculture*

Küçükbaş Hayvanlarda Dijital Refah Yaklaşımları

Özet

Günümüzde küçükbaş hayvan sağlığının bireysel, sürekli ve nesnel biçimde izlenmesine yönelik teknolojik gereksinimler, dijital tarım sistemleri ve yapay zekâ destekli veri işleme teknikleri ile karşılanabilir hâle gelmiştir. Hayvancılıkta refah göstergelerinin izlenmesi, sadece hayvan sağlığı açısından değil; aynı zamanda halk sağlığı, antibiyotik kullanımının kontrolü ve üretim verimliliği açısından da stratejik öneme sahiptir. Son yıllarda yapılan araştırmalar, giyilebilir non-invaziv biyosensörlerin küçükbaş hayvanlarda vücut sıcaklığı, kalp atış hızı, hareket düzeyi, çevresel stres faktörleri ve konum bilgisi gibi fizyolojik ve davranışsal parametreleri yüksek doğrulukla izleyebildiğini göstermektedir. Bu sensörlerden elde edilen çoklu veri akışlarının kablosuz iletişim sistemleri üzerinden bulut tabanlı platformlara aktarılması, gerçek zamanlı analiz olanaklarını mümkün kılmıştır. Bu teknolojik altyapı, makine öğrenmesi algoritmaları ile bütünleştirildiğinde, her bir hayvana özgü sağlık risk skoru ve bireysel refah değerlendirmesi gibi yenilikçi analiz biçimlerinin önünü açmaktadır. Bu sayede hastalıkların erken evrede teşhisi, doğuma yakın dönemlerin tahmini ve davranışsal anomalilerin tespiti olanaklı hâle gelmektedir. Benzer şekilde, Brusella spp. ve Coxiella burnetii gibi zoonoz etkenlerinin erken semptomları olan ateş artışı, letarji ve izolasyon davranışları da yapay zekâ destekli sistemlerle güvenilir şekilde ayırt edilebilmektedir. Küçükbaş hayvanlara özel geliştirilen sistemlerde sensör konfigürasyonlarının ergonomik, modüler ve düşük maliyetli olması büyük önem taşımaktadır. Kulak etiketi, göğüs bandı ya da sırt kemeri gibi farklı taşıyıcı formlarla uyumlu tasarımlar; hem hayvanın doğal davranışını bozmadan veri toplamaya olanak sağlamakta hem de uzun süreli saha uygulamalarında kullanıcı ve hayvan açısından konforu artırmaktadır. Hayvan refahının artırılması, antibiyotik kullanımının azaltılması, üreticiye iş gücü desteği sağlanması ve zoonotik hastalıklara karşı erken uyarı sistemlerinin geliştirilmesi açısından bu tür biyosensör ve yapay zekâ entegrasyonlu çözümler, hayvancılıkta dijitalleşmenin en somut çıktılarını sunacaktır. Bu bağlamda; ileri düzey sensör entegrasyonu, makine öğrenmesi modellerinin optimizasyonu ve bulut destekli mobil bildirim

sistemlerinin birlikte değerlendirilmesi, dijital refah izleme sistemlerinin başarısı açısından kritik unsurlar arasında yer almaktadır.

Anahtar Kelimeler: *Biyosensör, Yapay zekâ, Hayvan refahı, Dijital tarım*

Qualitative Management of Water Resources Through the Use of Treated Wastewater in Agriculture

Khelladi Malika[1] Debab Abdelkader[2]

[1]Department of process engineering, Faculty of science and technology, University Abdelhamid-ibn Badis, Mostaganem, Algeria
[2]Department of chemical engineering, Faculty of chemistry, University of science and technology of Oran, Oran, Algeria

Abstract

Advances in water and irrigation technologies for agriculture represent an unbelievable evolution towards a positive change in productivity while addressing water issues. Surface irrigation, sprinkler irrigation and drip irrigation are conventional methods that have certain drawbacks, such as wasting water and increasing labor costs. These conventional methods need to be accompanied by intelligent irrigation technologies, such as soil moisture sensors, weather-based controllers, precision irrigation systems and remote sensing. They enable crops to be supplied with a specific amount of water, and water to be used rationally, since it is supplied according to the needs of the crop or weather conditions. The adaptation of measures such as strategic watering, wastewater recycling, rainwater harvesting and the use of water-stress resistant crops are also presented as measures to cope with water scarcity. Clear examples of applications of these technologies are presented, which have helped to save water and increase agricultural yields worldwide. Since the 2020s, Algeria has been affected by climate change. These changes have resulted in increasingly hot summers, milder winters, less frequent and less intense rainfall, which has heightened the risk of drought. In addition, surface water quality has been compromised by various factors such as pollution, generating public health concerns. These challenges are projected to become even more frequent and intense in the future, so it is crucial to be prepared. As a result, adaptation is becoming crucial to meeting these growing challenges and ensuring community resilience in the face of future climate change. Preventive measures are needed to cope with variations in raw water quality, diversify supply sources, promote water conservation and wastewater reuse as a sustainable source of water and a substitute for chemical fertilizers for soil improvement. The objective of this communication is to present a general overview on the management of treated wastewater in Algeria with a specific emphasis on irrigation water supply for agriculture.

Key Words: *Climate Changes, Water Resources Management, Wastewater Reuse, Sustainable Development*

Generation of Vermıcompost from Invasive Alien Weed *Mimosa Pudica* by Employing *Eisenia Fetida*: Nutrient Content, Earthworm Fecundity and Effects on Crop Growth Attributes

Sajid Al Azwad[1], Nazmul Hossain[1]

[1]Department of Soil Science, Faculty of Biological Sciences, University of Chittagong, Chattogram, Bangladesh.

Abstract

To observe the nutrient status and earthworm fecundity of the produced vermicompost from invasive alien weed *Mimosa pudica* by employing *Eisenia fetida* and their impact on the growth attributes of Chinese cabbage (*Brassica rapa* var. pekinensis*)* and Radish (*Raphanus sativus*), this experiment was conducted in the crop field of the Department of Soil Science, University of Chittagong, Bangladesh during the Rabi seasons in 2023 and 2024. There were eighteen treatments (six were vermicompost, six were composted, and six were initial mixtures) for vermicomposting and eight treatments (one control, one NPK, and six others were vermicomposts) for pot experiment of Chinese cabbage and Radish. Three different bulking materials were used at two different ratios in the vermicomposting process. All the materials were collected from the University of Chittagong and nearby areas of campus. The soil contained 68 % sand, 11 % silt, and 21% clay. The OM content was only 1.44 %, and the TKN, TAP, TK, TCa, and TMg content was 0.91 %, 0.003 %, 0.29 %, 0.04 %, and 1.12 %, respectively. The vermicomposting was prepared from October 2023 to December 2023, and the pot experiment was conducted from January 2024 to February 2024. The results demonstrated significant differences in the ultimate biomass values ($p < 0.05$), highlighting the impact of treatment (feedstock) conditions on earthworm growth. Treatment T5 (MP: TDL: CD at 1:1:1 ratio) exhibited the highest biomass (11.35 ± 2.53 g). The concentrations of pH, EC, TKN, TAP, TK, TCa, TMg, and heavy metals were elevated in the vermicompost compared to their corresponding composts and initial mixtures. Conversely, the total OM content and C/N ratio were reduced in the vermicompost compared to their respective compost and initial mixtures, indicating the superior quality of the vermicompost. The pot trials revealed that the experimental soil was poorly fertility, and profitable crop cultivation without fertilizer treatment is not feasible. All fertilizer treatments enhanced crop growth as the number of leaves and the length of both roots and shoots in the two crops increased remarkably. However, there were significant variations among the fertilizer treatments. For example, the highest marketable yield (146 kg/ha) was obtained in Chinese Cabbage in the treatment T5 with an equal amount of *Mimosa pudica,* teak dry leaves, and cow dung. The trend of marketable yield was observed as follows, T5 (146kg/ha) > T1(140.10kg/ha) > T6(131.40kg/ha) > RFD (120.17kg/ha) > T2(111.20kg/ha) > T4 (54.50kg/ha) > T3 (33.10kg/ha) > T-CL (0.93 kg/ha). This indicates that Chinese Cabbage is sensitive to the toxicity of Ply plywood sawdust. Conversely, the highest marketable yield was obtained in Radish in the treatment of T_{RFD} (153.67 kg/ha), and the trend was T_{RFD} (153.67kg/ha) > T1 (138.87kg/ha) > T2 (132.37kg/ha) > T5 (124.13kg/ha) > T4 (121.13kg/ha) > T3 (114.63kg/ha) > T6 (109.97kg/ha) > $T_{Control}$ (17.93kg/ha). The result indicates that Radish is not sensitive to the toxicity of plywood sawdust. Data also revealed that the leaf area of Chinese Cabbage and Radish showed a substantial increase in yield under different treatments compared to the control ($T_{Control}$). For Chinese Cabbage the trend was T6 > T5 > T2 > T1 > T_{RFD} > T4 > T3 > $T_{Control}$ and for Radish the trend was T_{RFD} > T2 > T1 > T3 > T5 > T4 > T6 > $T_{Control}$. The above findings indicate that vermicompost produced from the invasive alien weed *Mimosa pudica* improves the overall growth and yield of Chinese cabbage and Radish.

Key Words: *Invasive alien weed, Vermicompost, Earthworms, Chinese cabbage, Radish.*

Use of Smart Technologies in Assessing Animal Welfare in Small Ruminant Breeding

Beyza Yılmaz [1]

[1]Department of Animal Production and Technology, Faculty of Agricultural Sciences and Technologies, Nigde Ömer Halisdemir University, Nigde, Türkiye

Abstract

Today, the technological requirements for individual, continuous, and objective monitoring of small ruminant health can be met through digital agriculture systems and artificial intelligence (AI)-driven data processing techniques. Monitoring welfare indicators in livestock is strategically important not only for animal health but also for public health, antibiotic use control, and production efficiency. Recent studies have demonstrated that wearable non-invasive biosensors can accurately track physiological and behavioral parameters in small ruminants, including body temperature, heart rate, activity levels, environmental stress factors, and location data. The transmission of these multi-source data streams to cloud-based platforms via wireless communication systems has enabled real-time data analysis, facilitating the collection of actionable intelligence. The integration of such technological infrastructure with machine learning algorithms has been demonstrated to facilitate innovative analytical approaches in the field of animal husbandry, including the development of individualised health risk scoring and personalised welfare assessment methodologies. Consequently, early diagnosis of diseases, prediction of parturition periods, and detection of behavioural anomalies become feasible. Similarly, the early symptoms of zoonotic pathogens, such as Brucella spp. and Coxiella burnetii, which include elevated body temperature, lethargy, and social withdrawal, can be reliably identified through the application of artificial intelligence-assisted systems. In systems designed specifically for small ruminants, the configuration of sensors is of particular importance, and must be ergonomic, modular, and cost-effective. The integration of designs that exhibit compatibility with diverse wearable configurations, including ear tags, chest bands and back harnesses, facilitates the unobtrusive collection of data, thereby ensuring minimal disruption to the animal's natural behaviour. Moreover, this approach enhances the level of comfort experienced by both animals and users in the context of extended field applications. The integration of biosensors and AI-based technologies is considered a significant outcome of digitalization in livestock farming, offering substantial contributions to improving animal welfare, reducing antibiotic use, supporting labour efficiency, and enabling early warning systems for zoonotic diseases In this context, the successful implementation of digital welfare monitoring systems is contingent on a number of factors, including the integration of advanced sensor technologies, the optimisation of machine learning models, and the incorporation of cloud-based mobile alert systems.

Key Words: *Biosensor, Artificial intelligence, Animal welfare, Digital agriculture, Small Ruminat*

Küçükbaş Hayvan Yetiştiriciliğinde Hayvan Refhanının Belirlenmesinde Akıllı Teknolojilerin Kullanımı

Özet

Günümüzde küçükbaş hayvan sağlığının bireysel, sürekli ve nesnel biçimde izlenmesine yönelik teknolojik gereksinimler, dijital tarım sistemleri ve yapay zekâ destekli veri işleme teknikleri ile karşılanabilir hâle gelmiştir. Hayvancılıkta refah göstergelerinin izlenmesi, sadece hayvan sağlığı açısından değil; aynı zamanda halk sağlığı, antibiyotik kullanımının kontrolü ve üretim verimliliği açısından da stratejik öneme sahiptir. Son yıllarda yapılan araştırmalar, giyilebilir non-invaziv biyosensörlerin küçükbaş hayvanlarda vücut sıcaklığı, kalp atış hızı, hareket düzeyi, çevresel stres gibi fizyolojik faktörlerinin yanı sıra konum bilgisinide yüksek doğrulukla izleyebildiğini göstermektedir. Bu sensörlerden elde edilen çoklu veri akışlarının kablosuz iletişim sistemleri üzerinden bulut tabanlı platformlara aktarılması, gerçek zamanlı analiz olanaklarını mümkün kılmıştır. Bu teknolojik altyapı, makine öğrenmesi algoritmaları ile bütünleştirildiğinde, her bir hayvana özgü sağlık risk skoru ve bireysel refah değerlendirmesi gibi hayvan yetiştiriciliğinde yenilikçi analiz biçimlerinin önünü açmaktadır. Bu sayede hastalıkların erken evrede teşhisi, doğuma yakın dönemlerin tahmini ve davranışsal anomalilerin tespiti olanaklı hâle gelmektedir. Benzer şekilde, Brusella spp. ve Coxiella burnetii gibi zoonoz etkenlerinin erken semptomları olan ateş artışı, letarji ve izolasyon davranışları da yapay zekâ destekli sistemlerle güvenilir şekilde ayırt edilebilmektedir. Küçükbaş hayvanlara özel geliştirilen sistemlerde sensör konfigürasyonlarının ergonomik, modüler ve düşük maliyetli olması büyük önem taşımaktadır. Kulak etiketi, göğüs bandı ya da sırt kemeri gibi farklı taşıyıcı formlarla uyumlu tasarımlar; hem hayvanın doğal davranışını bozmadan veri toplamaya olanak sağlamakta hem de uzun süreli saha uygulamalarında kullanıcı ve hayvan

açısından konforu artırmaktadır. Hayvan refahının artırılması, antibiyotik kullanımının azaltılması, üreticiye iş gücü desteği sağlanması ve zoonotik hastalıklara karşı erken uyarı sistemlerinin geliştirilmesi açısından bu tür biyosensör ve yapay zekâ entegrasyonlu çözümler, hayvancılıkta dijitalleşmenin en somut çıktılarını sunacaktır. Bu bağlamda; ileri düzey sensör entegrasyonu, makine öğrenmesi modellerinin optimizasyonu ve bulut destekli mobil bildirim sistemlerinin birlikte değerlendirilmesi, dijital refah izleme sistemlerinin başarısı açısından kritik unsurlar arasında yer almaktadır.

Anahtar Kelimeler: *Biyosensör, Yapay zekâ, Hayvan refahı, Dijital tarım, Küçükbaş Hayvan*

Effects of Traditional Transportation on the Behavior, Welfare, and Blood Profile of Local Chicken: A Case Study in Sudan

Saber Y. Adam[1, 2], Mohammed H. Jammaa[3, 4], Mohammed Rashid AL Makhmari[3], Davies M. Pfukenyi[5], Mohamed Osman Abdalrahem Essa[6], Hosameldeen Mohamed Husien[1, 6], Abdallah A. Basher[1,] Abdelkareem A. Ahmed[2,5,7,*], Demin Cai[1*]

[1]College of Animal Science and Technology, Yangzhou University, Yangzhou 225009, PR China
[2]Biomedical Research Institute, Darfur University College, Nyala, South Darfur State, Sudan
[3]Department of Public Law, Faculty of Law, Sohar University, Sultanate of Oman
[4]Department of Public Law, College of Law and Sharia, University of Nyala, Nyala, Sudan
[5]Department of Veterinary Science, Faculty of Animal and Veterinary Science, Botswana University of Agriculture and Natural Resources, Private Bag 0027, Gaborone, Botswana
[6]College of Veterinary Medicine, Albutana University, Rufaa, 22217, Sudan
[7]Department of Physiology and Biochemistry, Faculty of Veterinary Science, University of Nyala, Nyala, Sudan

*** Corresponding Author:**

Abdelkareem Abdallah Ahmed
Department of Physiology and Biochemistry, Faculty of Veterinary Science, University of Nyala
Nyala, Sudan
Email: kareemo151@gmail.com, kareemo151@vet.nyalau.edu.sd

Demin Cai
College of Animal Science and Technology, Yangzhou University, Yangzhou 225009, PR China
Email: demincai@yzu.edu.cn

Abstract

Indigenous chickens are raised in various rural areas in large quantities throughout Sudan. They must be transported over various distances, to centralized slaughter houses or other purposes. In this study, we examined indigenous chicken farmers' perceptions on chicken welfare during transportation linked this clinical examination. A total of 160 indigenous chickens (80 control+ 80 transported with their owners) were participated in this study. Our findings revealed that 69% and 88% of the farmers indicated that they are not knowledgeable about animal rights and animal welfare, respectively. The majority of the farmers 86% reported that they unaware of animal protection laws. Furthermore, the transported chickens significantly ($p < 0.05$) showed long tonic immobility duration compared to control chickens. Moreover, low pecking behavior was significantly ($p < 0.05$) showed in transported chickens compared to control, particularly in the day one of the experiment. In addition; the mean values of glucose, TWBCs, monocytes, basophils, eosinophils, H/L ratio, Hb, MCHC, and PLT were significantly ($p < 0.05$) higher in transported chickens compared to the controls. In addition, TNF-a, IL-1β, IL-2, IL-4, IFN-γ, IL-17, as well as ROS, MDA, Cort, Glucose, and total cholesterol were significantly ($p < 0.05$) higher in transportation chickens compared to control, while CAT, GSH, ATP, and SOD were significantly ($p < 0.05$) lower in transportation chickens compared to control. We conclude that the traditional transportation of indigenous Sudanese chickens affected their welfare associated with farmers' low perceptions of chicken welfare, and stress induced blood profile changes.

Key Words: *Animal welfare, Chicken transportation, Farmers, Oxidative stress*

Impact of *Moringa Oleifera* Leaf Polysaccharide on Growth Performance, Serum Biochemical Indices and Immune Functions in Broiler Chickens

Hosameldeen Mohamed Husien [1,2,*], Mohamed Osman Abdalrahem Essa [1], Saber Y. Adam [3], Ahmed A. Saleh [3,4] and Mengzhi Wang [2,5,*]

[1] College of Veterinary Medicine, Albutana University, Rufaa, 22217, Sudan.
[2] Laboratory of Metabolic Manipulation of Herbivorous Animal Nutrition, College of Animal Science and Technology, Yangzhou University, Yangzhou, 225009, Jiangsu, China.
[3] College of Animal Science and Technology, Yangzhou University, Yangzhou, 225009, Jiangsu, China.
[4] Animal and Fish Production Department, Faculty of Agriculture (Al-Shatby), Alexandria University, Alexandria City 11865, Egypt.
[5] State Key Laboratory of Sheep Genetic Improvement and Healthy Production, Xinjiang Academy of Agricultural Reclamation Sciences, Shihezi, Xinjiang 832000, China.
[*] Corresponding Authors:
Hosameldeen Mohamed Husien: hosamhusien29@yahoo.com; Mengzhi Wang: mengzhiwangyz@126.com

Abstract

Moringa oleifera (MO) is a versatile non-traditional feed supplement rich in bioactive compounds. The objective of this study was to examine the effects of MO leaf (MOL) polysaccharide (MOLP) intake on broiler chicken production and immune function. A polysaccharide with a molecular weight of 182.989 kDa was isolated from MOL in a previous study. Broiler chickens were allocated at random into four groups receiving varying doses of MOLP (0, 0.1, 0.2 and 0.4 g/kg feed) for three weeks. Feed intake (FI), average daily feed intake (ADFI), feed conversion ratio (FCR), and body weight gain (BWG) were monitored. Serological markers, including total protein (TP), albumin (ALB), globulin (GLO), albumin-to-globulin ratio (ALB/GLO), creatinine (CREA) were assessed. ELISA was used to measure immunoglobulin A (IgA), immunoglobulin G (IgG), interleukin-2 (*IL-2*), and tumor necrosis factor-alpha (*TNF-α*) mRNA expression. Results from days 21 to 28 demonstrated that the high dose of MOLP significantly enhanced BWG, ADFI, liver, and bursa indices compared to the control group. Additionally, blood biochemical analysis such as TP and GLO levels were elevated ($p < 0.05$). All MOLP treatments increased serum IgG concentrations and *IL-2* expression ($p < 0.01$). In conclusion, MOLP supplementation positively impacted broiler chicken growth performance and immune response, suggesting its potential as a valuable feed additive.

***Key Words**: Moringa oleifera, Polysaccharide, Broiler chickens, Growth performance, Immune response.*

Biomechanical Risk Assessment of Watermelon Harvesting Using AI-Based Motion Analysis

Peigeng Zhang[1]

[1]Agricultural and Biological Engineering, University of Florida, Florida, USA

Abstract

Watermelon harvesting is a physically demanding task that places workers at high risk for developing work-related musculoskeletal disorders (MSDs). While previous studies have explored MSDs in the agricultural area, there is a notable research gap specifically addressing MSDs in watermelon harvesting. This study aims to address this gap by evaluating the physical demands of watermelon harvesting in a field condition. The primary objectives are: (1) to identify the regions of the body most susceptible to injury during watermelon harvesting, and (2) to analyze physiological and biomechanical changes in the body while performing watermelon lifting tasks. Ten workers performed tasks associated with watermelon harvesting in the field with a camera recording. Kinematic data were analyzed using an AI based software. Joint angles were analyzed to examine statistical changes, contributing to a better understanding of the risks associated with watermelon harvesting.

Key Words:

Oral Administration of *Lactobacillus amylovorus* Alleviates Diarrhea and Partially Restores Gut Microbiota in Neonatal Goats

Mohamed Osman Abdalrahem Essa [1,2,], Liang Chen[1], Cheng Cheng [1], Layla Ahmed Mohammed Abdelhadi [1], Saber Y. Adam [3], Hosameldeen Mohamed Husien [2,3,†], Ahmed A. Saleh [3,4,] and Darong Cheng [1,5,*]

[1]College of Veterinary Medicine, Yangzhou University, Yangzhou, 225009, Jiangsu, China.

[2]College of Veterinary Medicine, Albutana University, Rufaa, 22217, Sudan.
[3]College of Animal Science and Technology, Yangzhou University, Yangzhou, 225009, Jiangsu, China.
[4]Animal and Fish Production Department, Faculty of Agriculture (*Al-Shatby*), Alexandria University, Alexandria City 11865, Egypt.
[5]Jiangsu Co-innovation Center for Prevention and Control of Important Animal Infectious Diseases and Zoonoses, Yangzhou, Jiangsu 225009, China.

Abstract

Neonatal goat (kid) diarrhea is an important health and economic concern for small-scale ruminant farms. The curative properties of Lactobacillus amylovorus as a treatment for kids with diarrhea and its effect on the composition of the gut microbiota were investigated in this study. Eight children with diarrhea were given *Lactobacillus amylovorus* orally,. We tracked gut microbial profiles, fecal consistency, and clinical symptoms. Using the Illumina HiSeq 2500 platform, 16S rRNA gene sequencing was performed on fecal samples. OTU clustering, taxonomic assignment, and alpha and beta diversity indices were used to examine the diversity and composition of microorganisms. Probiotic-treated kids all recovered properly from diarrhea in two weeks, while their untreated counterparts showed signs of clinical deterioration and gradual emaciation. With high-quality coverage across all samples, sequencing produced more than a million reads. 271 of the 8,519 OTUs that were found were shared by the groups. Children with diarrhea had far lower microbial richness, according to alpha diversity analysis, and this was only partially recovered after probiotic medication. Significant differences were observed in the Chao1, ACE, and Shannon indices between the treated and diarrheal groups ($p < 0.05$); however, there was no discernible group split in beta diversity. The healthy group had a higher abundance of *Verrucomicrobiota*, while *Firmicutes* and *Bacteroidota* predominated in all groups. While *Bacteroides* and *Akkermansia* predominated in the healthy and treated groups,at the genus-level analysis showed elevated levels of *Escherichia-Shigella* and *UCG-005* in children with diarrhea. In newborn goats, oral administration of *Lactobacillus amylovorus* successfully reduced diarrhea and partially restored gut microbial equilibrium. These results lend credence to its potential as a probiotic treatment for small ruminant enteric disease.

Key Words: *Goat , Lactobacillus amylovorus, Probiotic, Gut microbiota*

Harnessing Digital Agriculture for Food Science Innovation: A Review of Emerging Tools for Postharvest Quality, Safety, and Nutrition Enhancement

Chukwudi Ernest Ogbete, Miriam Ahunna Ofoeze

Biotechnology and Cassava Program, National Root Crops Research Institute, P.M.B 7006, Umudike, Abia State, Nigeria.

Abstract

Digital agriculture is transforming food systems by integrating advanced technologies into crop production, postharvest handling, and food processing. While significant progress has been made in precision farming, applying digital tools to enhance food science outcomes, particularly in postharvest quality, safety, and nutrition, remains less explored. This review looks at how emerging digital agriculture technologies such as Internet of Things sensors, near-infrared spectroscopy, artificial intelligence, and blockchain are shaping the future of food science. It emphasizes their roles in enhancing raw material quality, reducing postharvest losses, improving traceability, and enabling real-time monitoring of nutrient retention and food safety indicators. Case examples from root and tuber crops like cassava and sweet potato demonstrate potential applications in resource-limited settings. This paper also discusses how these tools can support functional food development and quality assurance during storage and processing. Key gaps in knowledge, technology access, and interdisciplinary integration are highlighted, along with recommendations for research, capacity building, and policy support. By establishing practical connections between digital agriculture and food science, this review aims to foster cross-sector innovation and guide efforts toward more sustainable and nutritious food systems.

Key Words: *Digital Agriculture, Food Science, Postharvest Quality, Nutritional Monitoring, Emerging Technologies*

Evaluating Large Language Models for Agricultural Injury Surveillance

Serap Gorucu[1], Jacob Muller[1], Daniel Petti[1], Changying Li[1], Matthew Pilz[2], Bryan P. Weichelt[2]

[1]Department of Agricultural and Biological Engineering, University of Florida, Gainesville, Florida, United States
[2]National Children's Center for Rural and Agricultural Health and Safety, National Farm Medicine Center, Marshfield Clinic Research Institute, Marshfield, Wisconsin, United States

Abstract

Collecting and disseminating data for agricultural injury surveillance typically depends on manual input and human review, making the process both time-consuming and labor-intensive. A prime example is AgInjuryNews (AIN), a public platform that compiles injury reports from news articles and investigations. Because the content is unstructured, AIN currently relies on human reviewers to extract relevant information. However, the rise of Large Language Models (LLMs) offers a promising avenue for automation. This study explored the potential of LLMs to assist in the reviewer role at AIN. Models evaluated include OpenAI's ChatGPT 3.5 and 4, along with a fine-tuned version of Llama 2, to assess their accuracy in extracting incident and victim-related details. Each model was tasked with identifying specific data points such as drug or alcohol involvement, time of incident, and victim demographics from a random sample of news articles previously reviewed by AIN staff. The fine-tuned Llama 2 emerged as the top performer, with an average accuracy of 93% and perfect scores in some categories. While none of the models were perfect, the results highlight the feasibility of integrating LLMs to streamline workflows, reduce resource demands, and enhance the efficiency of data collection and analysis.

Key Words: *Injury Surveillance, Large Language Models, Language Processing, Automation*

Expression Analysis of Nickel Responsive Genes in Sunflower Under Stress Conditions

Mahmood-ur-Rahman

Department of Bioinformatics and Biotechnology, Faculty of Life Sciences, GC University, Faisalabad, Pakistan
Corresponding Author E-mail: mahmoodansari@gcuf.edu.pk

Abstract

Heavy metal contaminated soils reduce the production and quality of crop plants. This situation is getting worsened with increasing population and food demand across the world. Many countries including Pakistan face severe environmental problems in most of the agricultural land areas. These severe environmental problems/heavy metal contaminations especially nickel (Ni) adversely affect the sunflower by reducing the yield of the plant substantially. The counterbalancing toxicity due to Ni requires complex mechanisms at molecular, biochemical, physiological, cellular, tissue, and whole plant level, which might manifest in terms of improved crop productivity. Different plant varieties possess variable tolerance to the stress conditions. One of the major adaptations to tolerate the Ni toxicity is enhanced production of anti-oxidant enzymes and the elevated expression of Ni responsive genes in plants. In this study, the expression of metal transporter genes was studied under Ni stress in sunflower. The sunflower plants were grown in pots having 10 Kg of soil each. There were four treatments (0, 50, 100, 200ppm) of Ni doses where 0 is control having no Ni. The experiment was conducted in triplicate using CRD. Total RNA was isolated from leaves at 28 days old plants. First strand cDNA was synthesized and expression of NRAMP1 and NRAMP3 genes was studied using Real Time PCR. The results indicated the up-regulation of NRAMP1 and NRAMP3 genes. This study may help to evaluate the role of NRAMP transporter genes in Ni toxicity tolerance in sunflower.

Key Words: *Expression analysis, Real Time PCR, Nickel, Heavy metal stress, NRAMP genes*

Digital Soil Mapping Classes in the Oued Righ Region Using a Random Forest Model (Southeastern Algeria)

Helimi Samia[1-2], Hamdi-Aissa Baelhadj[2], Koull Naima[1]

[1] Scientific and Technical Research Center for Arid Areas (CRSTRA), Biophysical Environment Station, Touggourt, Algeria.
[2] Labo. Biogeochemistry of Desert Areas, Univ Kasdi Merbah Ouargla, Algeria.

Abstract

Digital Soil Mapping (DSM) using the Random Forest (RF) model within Google Earth Engine (GEE) is an approach that leverages the platform's computational power and the availability of satellite data to predict and map soil classes. This method can contribute significantly to the sustainable management and valorization of soil resources in arid regions. In this study, DSM was applied to predict soil classes in the Oued Righ region, located in the northern Sahara of Algeria. A total of 334 soil profiles, covering approximately 700,000 hectares, were classified according to the USDA Soil Taxonomy (2014) from the order to the subgroup level. Twenty environmental covariates with a spatial resolution of 30 meters, representing topography, vegetation, and parent material, were derived from three main sources: topographic attributes (DEM), remote sensing data (Landsat 8), and a geological map. To assess the accuracy and validate the spatial prediction results, Overall Accuracy (OA) and the Kappa index were used. Validation results showed that the OA for the Order, Suborder, Great Group, and Subgroup levels were 90%, 83.02%, 75%, and 65.30%, with corresponding Kappa values of 0.80, 0.73, 0.56, and 0.47, respectively. The Multiresolution Valley Bottom Flatness Index (MrVBF), slope, elevation, Normalized Difference Vegetation Index (NDVI), Gypsum Index (Gyps_indx), and Soil Surface Salinity Index (Sali_indx) were among the top covariates used for soil class prediction at all levels of the USDA Soil Taxonomy. In conclusion, the Random Forest machine learning algorithm shows considerable potential for mapping soil classes in arid regions.

Key Words: *Machine Learning, Digital Soil Mapping (DSM), GEE, Random Forest, Oued Righ.*

Mardin İli Üzüm Üreticilerinin Tarımsal Bilinç Düzeyleri ve Eğitim İhtiyaçlarının Belirlenmesi

Bayyiğit, İ., Acıbuca, V.

Özet

Mardin ili, sahip olduğu mikroklima özellikleri ve tarımsal çeşitliliğiyle dikkat çeken önemli bağcılık merkezlerinden biridir. Bu çalışma, Mardin ilinde üzüm üreticilerinin bağcılık faaliyetlerindeki mevcut bilgi düzeylerini, tarımsal uygulamalarda karşılaştıkları sorunları ve eğitim ihtiyaçlarını ortaya koymayı amaçlamaktadır. Araştırmada tabakalı tesadüfi örnekleme yöntemine göre belirlenen, 136 üzüm üreticisiyle yürütülen anket çalışmaları sonucunda üreticilerin tarımsal bilinç düzeyleri, bilgi kaynakları ve eğitim ihtiyaçları değerlendirilmiştir. Araştırma sonuçları, katılımcıların %92,6'sının daha önce bağcılıkla ilgili herhangi bir eğitime katılmadığını göstermektedir. Üreticilerin öncelikli eğitim talepleri arasında hastalık ve zararlılarla mücadele ilk sırada yer almakta; bu durum, teknik bilgi eksikliğine işaret etmektedir. Ayrıca sosyal medya aracılığıyla bilgiye erişme isteğinin yüksek olması, dijital mecraların tarımsal öğrenme süreçlerinde artan rolünü ortaya koymaktadır. Veriler, aynı zamanda işletme ölçeği ile üretim amaçları arasında anlamlı bir ilişki olduğunu göstermektedir: küçük işletmelerde üzüm üretiminin %54,4'ü aile içi tüketime ayrılırken, bu oran büyük işletmelerde %16,9'a kadar düşmektedir. Bu farklılık, küçük ölçekli üreticilerin daha çok geçimlik, büyük işletmelerin ise ticari odaklı üretim yaptığını göstermektedir. Bu bulgular ışığında, bölgedeki üreticilerin teknik bilgiye dayalı karar alma yetkinliklerinin geliştirilmesi; yerel ihtiyaçlara duyarlı, modüler ve uygulamalı eğitim programlarıyla desteklenmelidir. Tarımsal yayım hizmetlerinin güçlendirilmesi, yalnızca üretim verimliliğini artırmakla kalmayacak; aynı zamanda kırsal kalkınmayı ve tarımsal sürdürülebilirliği de pekiştirecektir. Elde edilen veriler, bölgesel tarım politikalarının şekillendirilmesinde referans oluşturabilecek niteliktedir.

Anahtar Kelimeler: *Bağcılık, Tarımsal Yayım, Üzüm Üretimi, Eğitim İhtiyaçları, Sürdürülebilir Tarım*

The Potential of Microbial Fertilizers in Reducing Nutrient Losses in Hydroponic Systems

Tefide Kızıldeniz[1*], Ebrar Kanyılmaz[2]

[1] Department of Biosystems Engineering, Faculty of Agricultural Sciences and Technologies, Nigde Omer Halisdemir University, Niğde, Türkiye
ORCID Code: https://orcid.org/0000-0002-5627-1307
[2] Department of Biosystems Engineering, Faculty of Agricultural Sciences and Technologies, Nigde Omer Halisdemir University, Niğde, Türkiye
ORCID Code: https://orcid.org/0009-0003-7784-2281

* Corresponding author's e-mail: tkizildeniz@ohu.edu.tr

Abstract

Hydroponic systems, which allow soil-free cultivation with high water and nutrient efficiency, still face nutrient loss challenges, especially when chemical fertilizers are used intensively. This study aims to explore the potential of microbial fertilizers in minimizing nutrient losses and enhancing nutrient use efficiency in hydroponic farming. The central research question of this study investigates the effectiveness of microbial-based inputs in reducing nutrient leaching and enhancing plant performance in soilless cultivation systems. Microbial fertilizers, particularly those containing nitrogen-fixing and phosphorus-solubilizing bacteria, can enhance nutrient availability in the root zone. When integrated with organic amendments, they offer gradual nutrient release, reduce dependency on chemical inputs, and promote sustainable crop production. Literature findings suggest that microbial fertilizers may improve yield, reduce nitrate accumulation, and increase product quality in leafy vegetables such as lettuce and spinach. In conclusion, integrating microbial fertilizers into hydroponic systems represents a promising approach to reduce nutrient losses and support more sustainable and eco-efficient agricultural practices.

Key Words: *Microbial fertilizers, Hydroponic systems, Nutrient loss reduction, Soilless agriculture, Sustainable crop production*

Mechanisms of Lead Adsorption by Organo-Mineral Composite in Wastewater

Elbar Djenette[1], Elbar Chaima Yasmine[2]

[1]Center for Scientific and Technical Research for Arid Regions Biskra (CRSTRA) ALGERIA
[2]University Of Biskra ALGERIA

Corresponding author: elbardjenette@gmail.com

Abstract

Heavy metal contaminants in wastewater, particularly lead, pose a significant global environmental, ecological, and nutritional threat due to their toxicity. These metals originate from various industrial processes, including electroplating, dyeing, metallurgy, mining, and leather production. Lead metal is widely used in batteries, printing, dyes, fuels, photographic materials, and explosives, and its toxicity to humans is well-established.Among various wastewater treatment methods like chemical precipitation, ion exchange, electrodialysis, reverse osmosis, membrane filtration, irradiation, precipitation, and ozonation, adsorption stands out for its operational ease and simple design. Activated carbon is a widely used adsorbent in this process, known for its high thermal and optical stability, porous and rigid structure, mechanical stability, high surface-to-volume ratio, and purity. Schiff bases are effective extractants in solvent extraction due to their favorable physicochemical properties. They serve as important analytical reagents and ligands in coordination chemistry, with diverse donor atoms that facilitate simple, cost-effective determination of organic and inorganic substances. Their ability to form stable metal complexes is crucial in biological systems. Salicylideneaniline, a chelating extractant, has been used to extract various divalent metals. This research focuses on using activated carbon and the Schiff's base salicylideneaniline for efficient heavy metal separation from solutions, aiming to reduce environmental pollution and advance environmental chemistry and recovery techniques.Our studies optimize parameters such as pH, HSA concentration, and contact time to enhance the efficiency of the separation process for real-world applications. Effective lead adsorption occurs at an equilibrium pH of 6 to 6.7, with notably higher affinity for this AC-HSA blend, achieving a 70% yield in just 30 minutes. The stoichiometry of the organometallic complex corresponding to this metal was determined using the widely recognized log-log slope method.The kinetic study of the optimal adsorption of lead follows the Langmuir, Freundlich and Temkin isotherms, which exploit by a high affinity between the metal examined and the mixed of active carbon plus HSA, subsequently we have an excellent adsorption.

Key Words: *Lead ion's, Isotherms, Actived carbon, Schiff's base salicylideneaniline, Adorption*

Isolation, Characterization and Identification of Rhizobia from Root Nodules of French Bean (*Phaseolus vulgaris* L.) Grown in Acid Soils

Md. Abul Kashem[1], Khadeza Yasmin[1], Israt Jahan[1], Md. Imran Khan[1*] and Saima Sadia Jui[2]

[1]Department of Soil Science, Sylhet Agricultural University, Sylhet-3100, Bangladesh
[2] Department of Plant Pathology and Seed Science, Sylhet Agricultural University, Sylhet-3100, Bangladesh
*Corresponding author: imrankhan.ag@student.sau.ac.bd

Abstract

A pot experiment was conducted and repeated for two years in the field of the Department of Soil Science, Sylhet Agricultural University. Six treatments, viz. T_0 = Control (without *Rhizobium* inoculum) + Recommended Fertilizer (RF), T_1 = *R*. inoculum 15 g/kg seed + RF, T_2 = *R*. inoculum 30 g/kg seed + RF, T_3 = *R*. inoculum 45 g/kg seed + RF, T_4 = *R*. inoculum 60 /kg seed + RF and T_5 = *R*. inoculum 75 g/kg seed + RF were used following CRD with four replications. Lime application was done @ 2 t/ha. The local variety of french bean was used. Data were collected on nodule formation at the flowering stage of french bean. In addition, plant height, leaves, biomass, pod number, length and weight, seed number and weight at harvest during second year. The results showed that nodules were found in all treatments except the control treatment in first year. The *Rhizobium* bacteria were isolated from effective nodules grown on YEMA medium, showed white translucent, irregular in shape, with smooth surface, mucous producing, circular, convex, raised elevations, glister and non-motile colonies. The strains were found to be fast-growing. The range of colony size was 2-3.5 mm. The identification of isolated pure cultures through colony morphology analysis and biochemical properties includes gram staining (negative), bromothymol blue test (acid producing) and mannitol salt agar (positive). The second-year experiment showed that the plant height (41.97 cm), leaves (32.25 plant^{-1}), and biomass (60.44 plant^{-1}) were the highest in T_4 treatment. Additionally, the highest pods (60.44 plant^{-1}), pods weight (28.54 g pod^{-1}) and length (11.60 cm), seeds number (4.75 pod^{-1}) and weight (8.02 g pod^{-1}), effective nodules (109.25 plant^{-1}) were observed in T_4 treatment.

Key Words: *French bean, Nodules, Rhizobium inoculum, YEMA media.*

In-Silico Identification of Potential Targets for Sugarcane Smut Disease

Tayyaba Shaheen [1]

[1]Department of Bioinformatics and Biotechnology, Governemnt College University Faisalabad Pakistan, Pakistan

Abstract

Sugarcane (*Saccharum officinarum*) is a significant agro-industrial crop all over the world. It is polyploid crop with genomic size of 10GB. It is cultivated for its stalk in more than 119 countries, which accumulates sucrose. It contributes 60% of the raw sugar produced worldwide, the remaining comes from sugar beet. Sugarcane smut disease is caused by the fungus *Sporisorium scitamineum* that causes considerable yield losses. The symptoms for the sugarcane smut are black whip like structure instead of spindle leaves, emerging from the meristem, thin stalks, and leaves are more slender and much weaker. In present study potential targets were found against smut disease in sugarcane using subtractive genomic approaches. Molecular docking of drug target with available ligands helped to find a more suitable drug for sugarcane smut. The whole proteome of 11214 proteins of pathogen was retrieved from UniprotKB. Similar and repeated sequences were eliminated by CD-HIT server and only 8235 non-paralog sequences were obtained out of the total proteome. Homolog sequences were compared with host using NCBI-BLAST and 8079 non-homolog sequences were identified. DEG identified 452 essential proteins of pathogen. 3-D structures of two functional proteins ARL1-ADP-ribosylation factor and n-acetyltransferase were checked from Protein Data Bank but due to non-availability of their structures, 3D-Model of each protein was predicted using four homology modeling tools. Molecular docking was performed against the best selected protein model of ARL1-ADP-ribosylation factor with a library of 5000 phytochemicals and only ten compounds were selected which showed best interactions. Luteolin 7-O-beta-d-glucopyranoside compound was selected due to showing lowest RMSD and S-score with the target protein. Potential target identified in this study and docking results with different ligands can be developed more effective and suitable drug to eliminate the sugarcane smut disease caused by pathogen *S. scitamineum.*

Key Words: *Sporisorium scitamineum, Proteome, Essential Proteins, Pathway analysis, Subcellular localization, Druggable targets, Docking*

Statistical Machine Learning Models for Agricultural Injury Surveillance Data

Madison Moore[1], Serap Gorucu[1], Nikolay Bliznyuk[1]

[1]Department of Agricultural and Biological Engineering, University of Florida, Gainesville, Florida, United States

Abstract

The agricultural industry is the most hazardous industry in the United States, yet many fatal and non-fatal injuries go underestimated in government resources. This presentation demonstrates how machine learning models can analyze agricultural injury datasets to identify factors that increase injury likelihood and severity. Two datasets were used: the Florida Highway Safety and Motor Vehicles (FLHSMV) crash database and the Florida Trauma Registry. The FLHSMV data (2013–2021) included crashes involving farm vehicles (FVs) and farm labor transport vehicles (FLTVs). Logistic regression models identified crash characteristics that increased injury risk. The Florida Trauma Registry used to identify agriculture-related trauma cases from 2016–2021. To assess injury severity, an ordinal logistic regression and an ordinal random forest model were applied, with model performance compared to determine the better predictor. A Generalized Additive Model (GAM) was also used to analyze nonlinear effects of month and hour on injury outcomes. Results showed that crashes involving 744 FVs and 209 FLTVs occurring during darkness increased injury risk by 2.56 times compared to daylight crashes. The GAM confirmed the significant effect of time of day on injury outcomes. For the 930 agricultural injuries in the trauma registry, the ordinal logistic regression outperformed the ordinal random forest but had limited accuracy (0.53), only slightly better than predicting the most common minor injury category (0.45). These findings underscore the importance of machine learning approaches for uncovering and quantifying injury risk factors in Florida's agricultural sector. By leveraging logistic regression, ordinal random forest, and GAMs, the study was able to systematically identify how variables such as time of day and crash conditions amplify injury risk and severity. Ultimately, applying these models enables data-driven insights to inform evidence-based prevention strategies and elevate worker safety in this high-risk industry.

Key Words: *Agricultural Injury Surveillance, Generalized Additive Models, Logistic Regression, Machine Learning, Random Forest Model*

Investigating the Impact of Land Use Changes on Groundwater Quality in Arid and Semi-Arid Regions of Central Iran

Khorsandi Kouhanestani, Zohreh [1]

[1] Assistant Professor, Department of Natural Resources, Agricultural Sciences and Natural Resources University of Khuzestan, Mollasani, Khozestan, Iran

Abstract

Groundwater is recognized as one of the most vital water resources in arid and semi-arid regions. The recharge and discharge rates of groundwater aquifers changes can significantly affect groundwater quality. land use is one of the key factors on groundwater recharge and discharge rates. This study investigates the impacts of land use changes on groundwater quality in Najaf Abad plain, one of the groundwater plains in central Iran. water quality data such as electrical conductivity, total dissolved solids, nitrate, and major ion concentrations, over a 20-year period were analyzed, along this time period, land use maps were provided for different times. The results showed that in the studied plain, rangeland areas decreased during the investigation period, while agricultural and residential lands increased. Consequently, groundwater quality indicators changed. This study demonstrates that land use management and controlled groundwater extraction are necessary for preserving groundwater quality in arid and semi-arid regions.

Key Words: *Groundwater Quality, Land use changes, Arid and semi arid area*

Challenges and Safety Considerations in the Adoption of Autonomous Agricultural Vehicles

Farzaneh Khorsandi[1], Salah Issa[2], Serap Gorucu[3]

[1]Department of Biological and Agricultural Engineering, University of California, Davis, USA
[2]Department of Agricultural and Biological Engineering, University of Illinois Urbana-Champaign, USA
[3] Department of Agricultural and Biological Engineering, University of Florida, USA

Abstract

Agriculture remains one of the most hazardous industries in the United States. In addition to a high rate of injuries and fatalities, the sector faces an ongoing labor shortage and growing pressure to adopt piece-rate payment systems, further increasing risks for workers. To address these challenges, the industry is rapidly turning to digital agriculture and autonomous vehicles. However, the implementation of new technologies often outpaces the development of corresponding safety regulations and standards. This raises new concerns regarding the safety and health of workers working around these vehicles. Existing international guidelines—such as ISO 18497, ISO 25119 (functional safety), Australia's Code of Practice for Autonomous Agricultural Machinery, the UK's BS 8646:2023, and the European Union's Regulation (EU) 2023/1230—represent important steps forward. Still, they often remain too general and fail to address the practical risks associated with specific types of machines or tasks in agricultural environments. This presentation highlights current gaps and challenges in worker safety during the deployment of autonomous agricultural vehicles. It emphasizes the urgent need for targeted safety research and development of practical standards to ensure the well-being of those working alongside advanced technologies in agriculture.

***Key Words**: Agricultural Safety, Autonomous Vehicles, ISO 18497, Digital Agriculture, Occupational Health*

Perceptions and Effectiveness of Mobile Technology Among Extension Workers in Kwara State: Implications for Digital Extension Delivery in Nigeria.

Olumuyiwa Akin Olaniyi[1], Samson Abidoye[2], Micheal Dlamini

[1]Department of Agricultural Education & Extension, Faculty of Agriculture, University of Eswatini, Eswatini, Eswatini
[2]Department of Agricultural Extension & Rural Development, Faculty of Agricultural Sciences, Ladoke Akintola University of Technology, Ogbomoso, Nigeria

Abstract

This study investigated the perceptions and effectiveness of mobile technology among Extension workers in Kwara State, Nigeria. Using purposive sampling, sixty-seven Extension workers were selected for the study. Primary data were collected with the aid of a structured questionnaire and analysed using descriptive statistics (frequency counts, means, and charts). The Kruskal-Wallis test was employed to examine the formulated hypotheses. The results revealed that mobile phones were predominantly used for scheduling meetings with farmers to facilitate agricultural information dissemination (Mean = 2.79), exchanging SMS with researchers and farmers regarding pertinent agricultural practices (Mean = 2.79), and submitting daily activity reports to supervisors (Mean = 2.73). Mobile technology was mostly effective for scheduling farmers' meetings (Mean = 2.75), SMS communication on agricultural matters (Mean = 2.52), and accessing diverse information such as weather updates and market prices (Mean = 2.51). The identified constraints to effective mobile technology usage included limited network coverage (WMS = 2.52), irregular electricity supply for device charging (WMS = 2.48), and absence of institutional policies regulating mobile phone use within extension service delivery (WMS = 2.45). The Kruskal-Wallis test revealed no significant differences in effectiveness of mobile phone ($\chi^2 = 0.563$; $p > 0.05$) or extent of usage ($\chi^2 = 0.327$; $p > 0.05$) across zones. Conversely, perceptions differed significantly among zones ($\chi^2 = 6.453$; $p < 0.05$). It is recommended that extension institutions implement targeted training and workshops in zones exhibiting lower perception scores to bridge the skills gap and enhance mobile technology adoption for effective extension service delivery.

Key Words: *Effectiveness, Extension Workers, Digitalization, Perception.*

Tavukçulukta Ortaya Çıkan Altlıkların Yeniden Değerlendirilmesi: Çevresel ve Ekonomik Bir Yaklaşım

Asiye ÇETİNKAYA[1][0009-0009-5417-2477], Fatma YENİLMEZ[2,*][0000-0001-5470-7974] and Mikail BAYLAN[1][0000-0002-6299-5811]

[1]Çukurova Üniversitesi, Ziraat Fakültesi, Zootekni Bölümü, Adana, Türkiye
[2]Çukurova Üniversitesi, Tufanbeyli Meslek Yüksekokulu, Adana, Türkiye
*fyenilmez@cu.edu.tr

Özet

Tavukçuluk faaliyetlerinde yaygın olarak kullanılan altlık materyalleri, hayvan sağlığı, refahı ve hijyenik şartların sağlanması açısından kritik bir öneme sahiptir. Genellikle talaş, saman, pirinç kavuzu gibi materyallerden oluşan altlıklar, kümes hayvanlarının dışkısını absorbe ederek kümes içerisinde nem kontrolünü sağlar ve zararlı gaz oluşumunu azaltır. Üretim döngüsünün sonunda büyük miktarlarda organik içerikli atık oluşur ve bu durum, uygun şekilde yönetilmediği takdirde çevre kirliliğine yol açabilir. Tavukçuluk altlıkları; yüksek oranda organik madde, azot (N), fosfor (P) ve potasyum (K) içermeleri sebebiyle biyolojik dönüşüm süreçlerine oldukça elverişlidir. Bu nedenle son yıllarda, hem ekonomik olması, hem de çevreye olumlu katkılar sağlaması açısından altlıkların değerlendirilmesi konusu önem kazanmıştır. Elde edilen bulgular, tavukçuluk altlıklarının yalnızca bir atık değil, aynı zamanda önemli bir kaynak olarak değerlendirilmesi gerektiğini ortaya koymaktadır. Bu derleme çalışmasında tavukçuluk altlıklarının çevresel etkileri, alternatif değerlendirme yöntemleri ve ekonomiye katkıları tartışılmıştır.

Anahtar Kelimeler: *Tavuk altlığı, Organik atık, Sürdürülebilir tarım, Çevre yönetimi*

Re-evaluation of Poultry Litter: An Environmental and Economic Approach

Abstract

Litter materials commonly used in poultry farming play a critical role in ensuring animal health, welfare, and hygienic conditions. Typically composed of materials such as wood shavings, straw, and rice husks, poultry litter absorbs droppings, controls moisture within the coop, and reduces the formation of harmful gases. At the end of the production cycle, large amounts of organic waste are generated, which, if not properly managed, can lead to environmental pollution. Due to their high content of organic matter, nitrogen (N), phosphorus (P), and potassium (K), poultry litters are highly suitable for biological conversion processes. In recent years, the evaluation and reuse of these materials have gained importance for their economic benefits and positive environmental impacts. Findings indicate that poultry litter should not only be regarded as waste but also as a valuable resource. This review discusses the environmental impacts, alternative utilization methods, and economic contributions of poultry litter.

Key Words: *Poultry litter, Organic waste, Sustainable agriculture, Environmental management*

İklim Değişikliğinin Tavuklar Üzerindeki Etkisi

Fatma Yenilmez[0000-0001-5470-7974]
fyenilmez@cu.edu.tr
Çukurova Üniversitesi, Tufanbeyli Meslek Yüksekokulu, Adana, Turkiye
fyenilmez@cu.edu.tr

Özet

İklim değişikliği, tüm canlılarda olduğu gibi kümes hayvanları üzerinde de önemli etkilere sahiptir. Yükselen sıcaklıklar, değişen yağış düzenleri ve aşırı hava olaylarının artan sıklığı, tavukların sağlığını, verimliliğini ve refahını olumsuz etkiler. Yüksek sıcaklıklar, kümes hayvanlarında ısı stresine neden olarak yem tüketimini ve büyüme oranlarını azaltırken yumurta üretiminde düşüşlere yol açar. Hayvanlarda bağışıklık sisteminin zayıflaması, hastalıklara karşı duyarlılıklarını artırır. İklim değişikliği ayrıca patojen ve parazitlerin yayılmasını da etkileyerek hastalık risklerini daha da artırır. Sıcaklıklardaki artış ve yağışlardaki azalma, su kıtlığına ve yem bitkilerinin üretiminde düşüşe yol açarak yem maliyetlerinin artmasına neden olur ve bu da kümes hayvanı üretim giderlerinin ve ekonomik kayıpların önemli bir kısmını oluşturur. Bu olumsuz etkileri azaltmak için, yüksek sıcaklıkların fizyolojik etkilerini azaltmada ısıya dayanıklı tavuk melezlerinin geliştirilmesi ve yetiştirilmesi hayati önem taşıyacaktır. Kümes hayvanı yetiştiricileri ayrıca, ısı stresiyle mücadele etmek için kümeslerinde havalandırma ve soğutma sistemlerinin kullanımını artırmalıdır. Ayrıca, iklime dayanıklı yem bitkilerinin yetiştirilmesi ve su kaynaklarının verimli yönetimi, sektörün sürdürülebilirliği için hayati önem taşımaktadır. Sonuç olarak, bilimsel araştırmalara dayalı adaptasyon stratejilerinin geliştirilmesi ve üreticiler ile devlet politikacıları arasındaki işbirliğinin güçlendirilmesi, kanatlı sektörünün geleceği açısından kritik öneme sahiptir.

Anahtar Kelimeler: *İklim değişikliği, Tavuk, Verim, Bağışıklık*

The Effect of Climate Change on Chickens

Abstract

Climate change has significant effects on poultry, just as it does on all living beings. Rising temperatures, changing precipitation patterns and the increasing frequency of extreme weather events negatively effects the health, productivity, and welfare of chickens. High temperatures induce heat stress in poultry, reducing feed consumption and growth rates while leading to a decrease in egg production. The weakening of the immune system increases their susceptibility to diseases. Climate change also affects the spread of pathogens and parasites, further raising disease risks. The rise in temperatures and the decrease in rainfall contribute to water scarcity and a decline in feed crop production, leading to higher feed costs, which constitute a major portion of poultry production expenses and economic losses. To mitigate these negative effects, developing and breeding heat-resistant chicken hybrids will be crucial in reducing the physiological impacts of high temperatures. Poultry farmers must also enhance the use of ventilation and cooling systems in their henhouses to combat heat stress. Additionally, the cultivation of climate-resilient feed crops and the efficient management of water resources are essential for the sector's sustainability. Consequently, developing adaptation strategies based on scientific research and strengthening collaboration between producers and government policy makers are critical for the future of the poultry industry.

Key Words: *Climate change, Chicken, Performance, Immunity*

Integration of Precision Agriculture Data for Quality and Traceability in Food Production

Ezgi Demir Özer[1]

[1]Gastronomy and Culinary Arts, School of Applied Sciences, Cappadocia University, Nevşehir, Turkiye

Abstract

In today's food industry, concepts such as quality, efficiency, and sustainability are increasingly shaped by data-driven approaches. Precision agriculture offers real-time monitoring and analysis of key parameters such as soil composition, crop development, climatic conditions, and harvest timing, providing valuable input for food engineering processes. This study explores the integration of precision agriculture data into industrial food production systems, with a particular emphasis on its contribution to traceability and food safety. The digital data chain beginning in the field enables early prediction of raw material quality and allows production lines to be adjusted accordingly. For example, the Brix value of tomatoes or the protein content of wheat are critical parameters that directly influence product standardization and processing efficiency. By incorporating these values into production planning, food companies can implement predictive and smart manufacturing strategies rather than relying solely on time-consuming traditional quality tests. Digitally enabling traceability through precision agriculture data not only supports production optimization but also enhances transparency across the entire supply chain. When integrated with technologies such as blockchain, these systems offer end-to-end product traceability, strengthening consumer trust and significantly contributing to food security. This study presents examples of how precision agriculture data can be integrated into digital traceability systems within the food industry and discusses its potential impact on sustainable production models.

Key Words: *Precision agriculture, Traceability,Quality control, Product standardization, Data based production*

Gıda Üretiminde Hassas Tarım Verileriyle Kalite ve İzlenebilirlik

Ezgi Demir Özer[1]

[1]Gastronomi ve Mutfak Sanatları, Uygulamalı bilimler Yüksekokulu, Kapadokya Üniversitesi,Nevşehir, Turkiye

Özet

Gıda endüstrisinde kalite, verimlilik ve sürdürülebilirlik kavramları, günümüzde veri temelli yaklaşımlarla yeniden tanımlanmaktadır. Özellikle hassas tarım uygulamaları; toprak özellikleri, bitki gelişimi, iklim koşulları ve hasat zamanı gibi birçok parametreyi gerçek zamanlı olarak izleme ve analiz etme imkânı sunarak, gıda mühendisliği süreçlerine önemli girdiler sağlamaktadır. Bu çalışmada, hassas tarımdan elde edilen verilerin endüstriyel gıda üretim süreçlerine entegrasyonu ve bu entegrasyonun özellikle izlenebilirlik ve ürün güvenliği üzerindeki etkileri ele alınmaktadır. Tarladan başlayan dijital veri zinciri, hammaddenin kalitesini önceden tahmin etmeye ve üretim hattını bu doğrultuda ayarlamaya olanak tanımaktadır. Örneğin, domatesin şeker oranı (Brix) veya buğdayın protein oranı, üretim sürecinde kalite standardını doğrudan etkileyen parametrelerdir. Bu verilerin üretime entegre edilmesiyle, işletmeler kalite testlerini önleyici şekilde dijital olarak yönetebilmektedir. Hassas tarım verilerinin dijital sistemlerle izlenebilir hale getirilmesi, sadece üretim optimizasyonunu değil, aynı zamanda tedarik zincirinde şeffaflığı da desteklemektedir. Ürünlerin blokzincir teknolojileriyle takip edilebilir olması, tüketici güvenini artırmakta ve gıda güvenliğine önemli katkılar sağlamaktadır. Bu bildiride, hassas tarım verilerinin gıda endüstrisinde dijital izlenebilirlik sistemleriyle nasıl bütünleştirilebileceği ve bu yaklaşımın sürdürülebilir üretim modellerine nasıl katkı sunduğu çeşitli örneklerle tartışılacaktır.

Anahtar Kelimeler: *Hassas tarım, İzlenebilirlik, Kalite kontrol, Ürün standardizasyonu, Veri tabanlı üretim*

Isolation and Identification *of Citrobacter Freundii* from Diseased *Macrobrachium Nipponense*

Sheham Guma İbrahim[1]

[1]College of Agriculture, Yangzhou University, China

Abstract

Macrobrachium nipponense one of the most freshwater in world. but face may problem in farm. Out breaks of mass mortalities occurred in Macrobrachium nipponense farms in Jintan county, china. The bacterial isolates from M. nipponense show the same phenotypic traits and biochemical characteristics, and were identified as Citrobacter freundii according to biochemical characteristics and molecular identification. The infection test revealed that the strain YG2 was pathogenic to M. nipponense, and the half lethal dose (LD50) was 3.35 × 105 CFU/mL at 7d post-infection. Detection of virulence genes indicated that YG2 was positive for ompX, and LDH,cfa, ureG, ureF, ureE, ureD, viaB. Furthermore, the results of extracellular enzyme analysisdetect that the strain can produce protease, urease, amylase, lecithin, and hemolysin. Antibiotic resistance results showed that the isolate was resistant to ampicillin, cefazolin, cephalothin, cefoxitin, aboren, doxycycline, neomycin, and penicillin. This research provides a theoretical basis for a better understanding of the pathogenicity and resistance, which might contribute to the prevention of C. freundii in the future.

Key Words: *Citrobacter freundii, Pathogenicity, Macrobrachium nipponense, Antibiotics resistance*

Date and Lentil Powder: A Comprehensive Dietary Supplement

Elbar Djenette[1], Elbar Chaima Yasmine[2]

[1]Center for Scientific and Technical Research for Arid Regions Biskra (CRSTRA) ALGERIA

[2]University Of Biskra ALGERIA

Corresponding author: *elbardjenette@gmail.com*

Abstract

This natural and innovative supplement, meticulously crafted from a synergistic blend of finely ground date and lentil powder, stands as an exceptional source of sustained energy and a broad spectrum of essential nutrients. Designed for convenient oral consumption, this potent combination works effectively to bridge potential nutritional gaps within one's diet. It is readily available in a variety of user-friendly forms, including precisely dosed tablets, easy-to-swallow capsules, and palatable chewable gummies, offering flexibility for diverse preferences and needs.The lentil component of this supplement is a powerhouse of high-quality, plant-based protein. This makes it an invaluable asset for individuals aiming to support muscle growth and repair, particularly athletes or those engaged in regular physical activity. Furthermore, the significant protein content contributes substantially to increased satiety, helping individuals feel fuller for longer periods. The amino acid profile found in lentils complements various dietary patterns, ensuring a more complete nutritional intake. Dates, the other pivotal ingredient, offer a readily available and naturally derived source of quick energy. This energy primarily stems from their inherent natural sugar, which are easily assimilated by the body for immediate fuel. dates are also rich in dietary fiber, a crucial element for maintaining healthy digestive function and promoting regular bowel movements. The fiber content further aids in blood sugar regulation, preventing sharp spikes and crashes. Moreover, dates are packed with an impressive array of essential minerals. They are particularly noteworthy for their high potassium content, which plays a vital role in maintaining proper fluid balance, nerve function, and muscle contractions. Magnesium, another abundant mineral in dates, is integral for countless biochemical reactions in the body, including energy production and muscle and nerve function. Lastly, dates provide a significant amount of iron, a key mineral for red blood cell formation and oxygen transport throughout the body, making this supplement particularly beneficial for those at risk of iron deficiency. The combined nutritional profile of dates contributes not only to immediate vitality but also to long-term well-being and cellular health.

Key Words: *Dates, Lentil, Biochemical analyses, Sensorial analys, Dietary Supplement.*

AI-Assisted Generation of Datasets from Drone Imagery for Green Spaces

Nurgül Arısoy[1], Zekeriya Can Erbil[2]

[1]Department of Landscape Architecture, Faculty of Architecture and Design, Selcuk University, Konya, Türkiye
[2]Department of Landscape Architecture, Faculty of Architecture and Design, Selcuk University, Konya, Türkiye

Abstract

Artificial intelligence (AI) offers revolutionary innovations across various domains and has begun to play a significant role in the planning and management of green spaces. Due to their complex and multifaceted nature, urban green spaces can benefit greatly from AI's capabilities in data analysis and prediction, resource management, sensor integration, real-time monitoring, remote sensing and image processing, planning and decision support systems, as well as cost optimization. This study focuses on the creation and annotation of visual datasets required for AI applications in landscape architecture. High-resolution images captured at different altitudes using drone technology within a selected green space in Konya (Türkiye) enable the digital classification of vegetated areas. During the data processing and annotation stages, modern labeling and dataset development tools such as Roboflow, Labelbox, and Orange are employed to segment vegetation types (trees, shrubs, groundcovers, etc.) and turfgrass. The resulting annotated datasets are organized into standardized formats suitable for training deep learning algorithms (e.g., YOLOv8, U-Net) and provide a foundation for the advancement of digitization, green space management, and decision support systems in the field of landscape architecture. This study also highlights the technical and methodological challenges encountered during data collection and labeling and discusses how AI-based decision support systems can be integrated into sustainable landscape design processes. The findings aim to contribute to more effective and evidence-based design approaches, particularly in spatial analysis and green space management. Thus, the research demonstrates how data-driven approaches can be used in landscape architecture and provides a reference framework for future modeling and automation studies.

Key Words: *Landscape Architecture, Artificial Intelligence, Green Spaces, Image Processing, Data Annotation*

Comparative Analysis of Traditional and AI-Assisted Visualization Techniques in Interior and Exterior Design

Zekeriya Can Erbil[1], Ali Akçaova[1]

[1]Landscape Architecture, Faculty of Architecture and Design, Selçuk University, Konya, Türkiye

Abstract

This study aims to establish a common ground between the disciplines of landscape architecture and interior architecture by evaluating the advantages and disadvantages of AI-assisted visualization techniques in comparison to traditional visualization methods. Within the scope of the study, a previously completed landscape design project and an interior design project will be selected; these projects will be re-visualized using both traditional methods (such as hand drawing, CAD, 3D rendering, etc.) and AI-supported visualization tools (e.g., Midjourney, DALL·E). The use of visualization tools will be limited to the five applications most preferred by the survey participants. The resulting visuals will be compared based on criteria such as aesthetic value, realism, perception of scale, and material expression. These visuals will then be presented to three different user groups (expert academics, private sector professionals, and undergraduate students trained in design), and qualitative and quantitative data will be collected using a 5-point Likert scale method. Based on the feedback from participants, the potential use, perceived value, and limitations of AI tools in the design process will be discussed. This study aims to reveal the impact of AI-assisted visualization tools on the design process from an interdisciplinary perspective. The level of success of AI-generated visuals in terms of aesthetic value, realism, perception of scale, and material expression will be analyzed based on evaluations from different user groups, and the strengths and limitations of these tools will be identified. In addition, by comparing these outputs with those produced using traditional methods, the study aims to generate insights into how AI tools can play a complementary role in design education, professional practice, and creative processes. Ultimately, the findings of this research are expected to lead to recommendations on how AI-based visualization tools can be used more efficiently and consciously within design disciplines such as landscape architecture and interior architecture.

Key Words: *Artificial Intelligence, Interior Architecture, Landscape Architecture, Design Process, Visualization*

Statistical Machine Learning for Improved Detection and Uncertainty Quantification of Pathogenic E. Coli in Hydroponic Irrigation Water Using Impedimetric Systems

Hanyu Qian[1], Eric McLamore[2], Nikolay Bliznyuk[1]

[1]Department of Agricultural & Biological Engineering, University of Florida, Gainesville, FL, USA
[2]Department of Agricultural Sciences, Clemson University, Clemson, SC, USA

Abstract

The reuse of alternative water, such as untreated surface water, for irrigation presents a sustainable solution to water shortages but elevates the risk of bacterial contamination in fresh produce. Consequently, the accurate and rapid identification of pathogens like Shiga-toxin producing Escherichia coli (STEC) is critical for safe water resource management. This work develops an advanced data analytical methodology for predicting pathogen concentrations in complex matrices. We employed an impedimetric electrochemical aptasensor with gold interdigitated electrodes to detect E. coli O157:H7 in surface water intended for hydroponic lettuce irrigation. A statistical machine learning (SML) framework was developed to assess and optimize prediction accuracy across various classes of SML models. The application of this framework facilitated the selection of a superior analytical technique, which resulted in a minimum 20% reduction in the test set root mean square error (RMSE) for E. coli O157:H7 concentration prediction when compared to the classic analytical approach. Further research directions, including the application of Bayesian methods for uncertainty quantification, will also be discussed.

Key Words: *Bacteria, Machine learning, Pathogen detection, Statistics, Smart agriculture*

Toward Sustainable Poultry Nutrition: A Review of Agricultural By-Product and Waste Valorization

Chaıb Eddour Ahmed Readh[1], Lıtım Miloud[1], Bouderoua Kaddou[2]

[1]Department of Agricultural Sciences, Faculty of Natural and Life Sciences, at the Agronomy Higher school Mostaganem, Algeria.

[2]Department of Agricultural Sciences, Faculty of Natural and Life Sciences Faculty, at the University of Mostaganem, Algeria.

Abstract

In recent years, the substantial rise in agri-food production has led to the accumulation of large volumes of agro-industrial wastes and by-products, thereby exacerbating environmental pollution. Consequently, the reutilization of these non-edible by-products as alternative feed ingredients in animal nutrition has gained significant attention. This approach not only reduces reliance on conventional feedstuffs but also alleviates land-use pressure and mitigates food-feed competition, thus supporting environmental, economic, and social sustainability. Moreover, these underutilized resources are rich in bioactive compounds such as polyphenols, dietary fiber, essential oils, vitamins, and minerals. Their valorization has been increasingly promoted through innovative strategies aligned with the European Union's circular economy and green biorefinery models. Among these strategies, the development of cost-effective, nutritious, and sustainable animal feeds represents a key solution. Furthermore, various fruit and vegetable by-products such as dried orange pulp from the fruit juice industry, olive pomace, pomegranate husks, and tomato processing residues have been successfully incorporated into poultry diets. These by-products not only serve as functional feed ingredients but also exhibit nutraceutical properties that enhance poultry health and welfare. In this context, the present review aims to provide a comprehensive synthesis of the potential of diverse agri-food wastes and by-products for poultry feeding. It explores their bioactive components, their functional roles as feed additives, and the associated health-promoting effects, thereby underscoring their relevance in advancing sustainable poultry production.

Key Words: *Fruit juice industry leftovers, Dried orange waste, Olive oil industry by-products, Pomegranate by-products, Tomato processing by-products, Bioactive compounds*

Investigation of Germination and Initial Development Periods of Sorghum (*Sorghum Vulgare* L.) Seeds with Different Pretreatments under Controlled Conditions

Aslı Sözeri[1]

[1]Department of Field Crops, Faculty of Agriculture, Ankara University, Ankara, Türkiye

Abstract

The study aimed to investigate germination criteria and seedling development by applying five different pretreatments to sorghum seeds: PEG (20%), Mannitol (6%), Sorbitol (10%), distilled water, and a control. The study was conducted in 2023 at the laboratory of the Field Crops Department of the Faculty of Agriculture at Ankara University, using a randomized plot design with four replications. After soaking the seeds in the treatment media for 24 hours, they were dried on blotting paper for another 24 hours and allowed to germinate under controlled conditions. Germination rate and strength, shoot and radicle length, shoot fresh and dry weight, and radicle fresh and dry weight of the seeds monitored under laboratory conditions were recorded. It was noted that the characteristics examined in the germination of millet seeds under controlled laboratory conditions produced significant differences in terms of priming treatment. According to laboratory results, it was determined that primed seeds showed a more significant increase in germination speed and germination power compared to the control, and that PEG 20% and distilled water applications had a positive effect on the examined traits.

Key Words:

APP: Profitability Determination of Onion Cultivation

Carlos Robles-Rojas[1]

[1] School of Agribusiness, Costa Rica Institute of Technology (TEC), Cartago, Costa Rica. Email: crobles@itcr.ac.cr
Presented by: Dr. Carlos Robles Rojas

Abstract

The onion production sector in the northern zone of Cartago faces significant limitations in accessing technological tools that support timely and reliable decision-making. Existing platforms in the market do not adapt to the conditions of national production, creating gaps in efficiency, profitability, and sustainability. The objective of this study was to develop and implement a technological platform that enables producers associated with the National Horticultural Corporation to determine the profitability of their onion crops and improve their economic management processes. The methodology followed a participatory and results-oriented approach. Farm visits were conducted to analyze production activities, collect and validate field data, and contrast them with economic factors. Based on this information, a platform was designed and tested using Azure, complemented by mobile applications, which integrates productive and economic data to provide farmers with personalized, real-time recommendations for crop management. The platform offers farmers access to accurate and practical economic information, strengthening strategic decision-making. Its implementation is expected to increase the efficiency, profitability, and sustainability of onion production in the region. In conclusion, this digital tool represents a strategic resource to optimize productivity, enhance economic management, and contribute to the sustainable socioeconomic development of the northern zone of Cartago.

Key Words: *APP, Onion, Agribusiness, Economic Information*

ehalmal.com as an Innovative Business Model in the Digital Transformation of Agriculture

Murat İnan [1]

[1] Director of ehalmal.com

Abstract

This article examines ehalmal.com, founded in 2018 based on more than 15 years of practical commercial experience, as an innovative business model for the digital transformation of the agricultural sector. Focusing on inefficiencies in the traditional supply chain, the platform has created a digital ecosystem that directly connects producers with consumers. The research analyzes the multidimensional impacts of ehalmal.com on agricultural economics. The findings reveal that the platform enhances market efficiency, increases producers' profit margins, and supports rural development. Through transparent pricing and data analytics, information asymmetry is eliminated, ensuring a fair marketplace for all stakeholders. As a success story in digital marketing and entrepreneurship, ehalmal.com demonstrates that new business models and economic values can be generated in the agricultural sector. The model offered by the platform serves not only as a commercial success but also as a prototype that sheds light on the future of agricultural production. This study argues that ehalmal.com constitutes a model for digital agricultural marketing and economic development. The congress presentation will open a discussion on the details of this model and its future potential.

Key Words: *Digital agriculture, E-commerce, Supply chain, Rural development, Agricultural economics, Entrepreneurship*

ehalmal.com: Dijital Tarım Dönüşümünde İnovatif Bir Model ve Tarım Ekonomisine Etkileri

Özet

Bu makale, 2018 yılında 15 yılı aşkın pratik ticari deneyime dayanılarak kurulan ehalmal.com'u, tarım sektörünün dijital dönüşümüne yönelik yenilikçi bir iş modeli olarak incelemektedir. Geleneksel tedarik zincirindeki verimsizliklere odaklanan platform, üretici ile tüketiciyi doğrudan buluşturan dijital bir ekosistem oluşturmuştur. Araştırma, ehalmal.com'un tarım ekonomisi üzerindeki çok boyutlu etkilerini analiz etmektedir. Bulgular, platformun pazar verimliliğini artırarak üretici kâr marjlarını yükselttiğini ve kırsal kalkınmayı desteklediğini göstermektedir. Şeffaf fiyatlandırma ve veri analitiği sayesinde bilgi asimetrisi ortadan kalkmakta, tüm paydaşlar için adil bir pazar yeri sağlanmaktadır. ehalmal.com, dijital pazarlama ve girişimcilik alanında bir başarı hikayesi olarak, tarım sektöründe yeni iş modelleri ve ekonomik değerler yaratılabileceğini kanıtlamaktadır. Platformun sunduğu model, sadece ticari bir başarı olmanın ötesinde, tarımsal üretimin geleceğine ışık tutan bir prototip teşkil etmektedir. Bu çalışma, ehalmal.com'un dijital tarım pazarlaması ve ekonomik kalkınma için bir model teşkil ettiğini savunmaktadır. Kongre sunumu, bu modelin detaylarını ve gelecekteki potansiyelini tartışmaya açacaktır.

Anahtar Kelimeler: *Dijital tarım, E-ticaret, Tedarik zinciri, Kırsal kalkınma, Tarım ekonomisi, Girişimcilik.*

Smart Harvests: Deep Learning and the Future of Agriculture

Yonis Gulzar[1]

[1]Department of Management Information Systems, College of Business Administration, King Faisal University, Al-Ahsa 31982, Saudi Arabia, ygulzar@kfu.edu.sa

Abstract

Agriculture stands at the crossroads of tradition and technology. As the global demand for food continues to rise, deep learning is emerging as a transformative force capable of reshaping how we cultivate, process, and consume agricultural products. The keynote Smart Harvests: Deep Learning and the Future of Agriculture explores the intersection of artificial intelligence and agriculture, with a focus on fruit classification as a gateway application. Advances in data augmentation, transfer learning, and lightweight architectures have enabled deep learning models to achieve unprecedented accuracy in real-time classification, supporting smarter quality control, sustainable farming, and global food security. However, challenges remain - including limited datasets, computational costs, and model generalization - highlighting the need for human-AI collaboration, interpretable systems, and scalable deployment in the field. By bridging research insights with practical applications, the keynote demonstrates how deep learning can drive a new era of “smart harvests,” ensuring efficiency, resilience, and sustainability in agriculture.

Key Words: *Deep learning, Artificial intelligence, Sustainable farming*

Teknolojik Gelişmelerin Kuluçka Makinesi Gelişimi Üzerine Etkisi

Melis Yağlı1, Hasan Eleroğlu2, Recep Gümüş3

Sivas Cumhuriyet Üniversitesi Veteriner Fakültesi Hayvan Besleme ve Beslenme Hastalıkları Anabilim Dalı, TÜRKİYE [1]
https://orcid.org/0009-0003-0285-9994
Sivas Cumhuriyet Üniversitesi Sağlık Bilimleri Meslek Yüksekokulu, TÜRKİYE[2] https://orcid.org/0000-0002-1032-9833

Sivas Cumhuriyet Üniversitesi Veteriner Fakültesi Hayvan Besleme ve Beslenme Hastalıkları Anabilim Dalı, TÜRKİYE [3]
https://orcid.org/0000-0002-8812-191X

Özet

Bu çalışmada, kuluçka makinelerinin tarihi gelişimini, işleyiş prensiplerini ve günümüzdeki teknolojik evrimini incelenmiştir. Kuluçka makineleri, yumurtaların uygun sıcaklık, nem ve havalandırma koşulları altında yapay ortamda gelişmesini sağlayan cihazlar olarak bilinmektedir. Özellikle artan dünya nüfusu ve gıda talepleri doğrultusunda kanatlı hayvan üretiminde yaygın bir şekilde kullanılmaktadır. İlk kuluçka makinelerinin Mısır ve Çin'de yaklaşık 4.000 yıl önce ortaya çıktığına dair veriler bulunmaktadır. Zaman içinde, özellikle 18. yüzyıldan itibaren yapılan bilimsel çalışmalarla modern kuluçka makinelerinin temelleri atılmıştır. Günümüz de kuluçka makineleri, sıcaklık, nem ve havalandırma gibi kritik faktörlerin kontrol edilmesini sağlayan gelişmiş teknolojilerden oluşturulmuştur. Bu makineler, yumurtaların en uygun şartlar altında gelişmesini sağlamak amacıyla sıcaklık, nem, havalandırma gibi sistemleri içermekte, ayrıca otomatik döndürme mekanizmaları aracılığıyla gelişim takip edilmektedir. Kuluçka makinelerinin verimliliğini etkileyen faktörler arasında sıcaklık, nem oranı, hava sirkülasyonu ve oksijen seviyeleri büyük önem taşımaktadır. Son yıllarda kuluçka makinelerindeki dijitalleşme ve otomasyon alanındaki ilerlemeler, sıcaklık, nem ve döndürme sıklığını embriyo gelişim aşamalarına göre değerlendirmeyi mümkün kılmaktadır. Gelecekte, kuluçka makinelerinin mobil cihazlarla uzaktan izlenmesi ve yönetilmesi, enerji verimliliği sağlanarak çevresel etkilerin azaltılması beklenmektedir.

Anahtar Kelimeler: *Kuluçka Makinesi, Kanatlı Hayvanlar, Teknolojik Gelişim*

Abstract

This study examines the historical development, operational principles, and technological evolution of incubators. Incubators, devices that allow eggs to develop in an artificial environment with proper temperature, humidity, and ventilation conditions, are widely used in poultry farming, especially in response to the growing world population and food demand. Data suggests that the first incubators appeared about 4,000 years ago in Egypt and China. Over time, particularly from the 18th century onwards, scientific studies laid the foundations for modern incubators. Today, incubators are equipped with advanced technologies to control critical factors such as temperature, humidity, and ventilation. These machines contain systems for temperature, humidity, ventilation, and turning mechanisms, as well as sensors that monitor embryo development. Factors influencing incubator efficiency include temperature, humidity levels, air circulation, and oxygen levels. Recent advancements in digitalization and automation of incubators have enabled the monitoring and adjustment of temperature, humidity, and turning frequency based on the developmental stages of embryos.
In the coming years, incubators are anticipated to be controlled and monitored remotely via mobile devices, improving energy efficiency and minimizing environmental effects.

Keywords: *Incubator, Poultry Animals, Technological Development*

Giriş

Kuluçka makineleri, özellikle kanatlı hayvan üretiminin verimliliğini artırmak amacıyla tasarlanmış, yumurtaların yapay ortamda gelişimini sağlayan cihazlardır (Çakır ve Çalışır, 2007). Kuluçka makinelerinin buluş tarihine bakıldığında eski zamanlara dayandığı ve teknolojik gelişmeler ile birlikte insan gücü gerektirerek kullanılan makinelerin yerine daha otomatik ve verim gücü yüksek makinelerin geliştirildiği görülmektedir. (Boleli ve ark. ,2016). Kuluçka makinesinin bilinen ilk keşfi olarak Antik Mısır ‘da o döneme uygun olarak kullanılan ısıtma yöntemleri ile ve küçük bölmelerle kümes mantığında bir alan oluşturularak gelişim planlanmıştır (Paniago, 2005). Günümüzde kuluçkahane adı verilen kuluçka merkezlerinde kuluçka sürecinin adım adım gelişimi için ayrı bölümler oluşturulmuştur. Bu bölümler sırası ile dezenfeksiyon bölümü, yumurta kabul ve depolama bölümü, gelişim bölümü, transfer ve ışıkla döllülük kontrol bölümü, çıkım bölümü, cinsiyet ayrımı ve aşılama bölümü, sınıflandırma ve bekleme bölümü, tırnak ve gaga bakım bölümü, yıkama bölümü yükleme bölümü ve atıklar bölümü olmak üzere kullanılan merkezlerde benzer varyasyonlar ile oluşturulmaktadır (Elibol ve Türkoğlu ,2014).

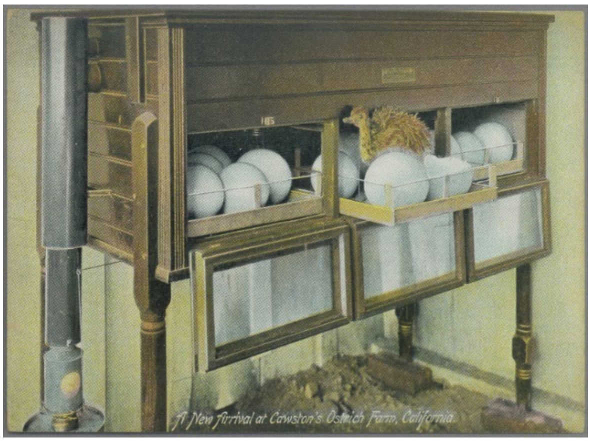
Gelecek dönemde öngörülen çalışmalarda ise gelişen teknoloji ile daha inovatif ve yapay zekaya dayanan gelişmelerle daha pratik ve verim oranı yüksek çalışmalar yapılacağı ön görülmektedir (Grimaldi & Grandi, 2005).

Kuluçka Makinesinin Gelişim Süreci

Kuluçka makinesi, yumurtaların içinde yer alan embriyonun uygun gelişim sıcaklık, havalandırma koşulları ve nem altında yapay olarak gelişimini sağlayarak civciv üreten cihazdır. Nüfus artışına paralel olarak artan besin gereksinimlerini karşılamak için kanatlı hayvan üretiminde kuluçka makinesi kullanımı çoğalmıştır. Bu amaçla tavuk ve yetiştiriciliği yapılan diğer kanatlı hayvanların yumurta gelişimleri kuluçka makineleri ile sağlanmaktadır (Çakır ve Çalış, 2007). Kuluçka makinelerinin tarihçesi, artan tüketim ihtiyacına bağlı olarak ve gıda tüketiminde yumurtanın içeriğinden kaynaklanan gereksinim ihtiyacı ile insanların üretim çalışmalarına dayanır. İlk kuluçka makinelerinin Mısır ve Çin'de yaklaşık 4.000 yıl kadar eski bir tarihe dayandığına dair bulunan kanıtlarda ana maddesi kerpiç olan fırın benzeri yapılar ile yumurtaların istenilen sıcaklıkta saklanılması sağlanıyordu (Smith, 2005). Bu yapılar küçük odacıklar şekilde tasarlanmış ve havalandırma sağlanması için alanlar içermekteydi (Yaşrin ve Sert, 2021). Çin'de kül ve pirinç kabuğu kullanılarak yumurtalarda sabit sıcaklık uygulaması çalışmaları yapılmıştır (Zhang, 2010). 18. yüzyıl itibari ile artan bilimsel çalışmalarla birlikte modern kuluçka makinesinin ilk adımları atılmaya başlanmıştır. Fransa'da 1749 yılında Fransa'da termometre kullanarak başarılı sonuçlar elde edilmiş (Yaşrin ve Sert, 2021).

İngiltere'de 1609 yılında Drebbel tarafından ilk termostatlı kuluçka makinesi modellemesi yapılarak kuluçka makinesi gelişimine büyük bir katkı sağlanmıştır (Hsueh ve Collins· 2019).

Özellikle Avrupa 'da artan bu gelişmelerle birlikte 19. yüzyılda, James Sharp tarafından ilk termostatlı kuluçka makinesi geliştirilmiş ve bu da kuluçka makinelerinin gelişimine büyük bir katkı sağlamıştır (Brown, 1987). 1991 yılına gelindiğinde ise elektrikle çalışan ilk otomatik kuluçka makinası yapılmış ve bugünkü teknolojinin ilk adımı atılmıştır (Yaşrin ve Sert, 2021).



Şekil 1. İlk Termostatlı Kuluçka Makinesi Örneği
(Michael Rieder , 2014)

Termostatlı kuluçka makinesinin çalışma mekanizması aslında sıcak su sayesinde kuluçka koşulları için sağlanması gereken sıcaklık ve nem oranının sağlanmaya çalışılması temeline dayanmaktaydı. Doğal yaşamda anne tarafından sıcak ve nem oranı sağlanarak yumurta içerisindeki civcivin gelişimi sağlanmaktadır. Kuluçka makinesindeki gelişmelerin başlangıcı Amerika Birleşik Devletleri'ne dayanırken kuluçka merkezlerinin hızlı büyümesinin ardından Avrupa ve Asya'ya yayılmıştır. Amerika Birleşik Devletleri'nde bu çalışmaların Stanford Araştırma Parkı New York ve Batavia'da kurulan Endüstriyel Merkezinde yürütüldüğü bilinmektedir (Hackett ve Dilts ,2004). Dünya genelinde değerlendirme yapıldığında ülkelerin yerel sermayeleri tarafından desteklenen kuluçka merkezi sayılarının 7000'den fazla olduğu ön görülmektedir (Weele ve ark., 2017). İlerleyen zamanlarda tavuk eti tüketim talebinin artması ve bununla birlikte gelişen teknolojik çalışmalar ile kuluçka makinelerine olan ilgi de artmıştır. Amerika Birleşik Devletleri'nde teknoloji ve sanayileşmenin gelişimiyle birlikte kuluçka makinesinde de teknolojik olarak ilerlemeler kaydedilmeye başlamıştır. Son zamanlarda kuluçka modelleri evrilerek sanal modellerin oluşturulması ve ayrıca, hızlandırıcı 'accelerator' olarak literatüre giren yeni bir tür kuluçka makinesi türü de ortaya çıkmıştır. İlk çıkan hızlandırıcı olarak bilinen kuluçka makinesi modeli 2005 yılında Paul Graham tarafından meydana getirilmiştir. Günümüzde kullanılan kuluçka makineleri son teknoloji ile geliştirilmiştir. Kuluçkadan istenilen veriminin alınabilmesi için gerekli olan başlıca koşullar arasında; ısı, nem oranı, havalandırma koşulları, ortamdaki hava sirkülâsyonu, yumurtaların döndürülme açıları ve gerekli oksijen oranının sağlanması bulunmaktadır. Tarım ve Orman Bakanlığınca kabul edilen ilkeler şu şekilde sıralanabilir (Tarım ve Orman Bakanlığı);

Yumurtaların kuluçka makinesinde bulunup büyüme ve gelişimi geçirdikleri süre boyunca hareket halinde olması gerekmektedir. Bu konuda tercih edilen hareket şekli yumurtaların çevrilmesi şeklinde olmaktadır. En yüksek verime 45 derecelik döndürme açısında ulaşılmaktadır (Erensayın,1991). Yumurtaların gelişim dönemi ilk 18 günde meydana gelmektedir. Bu yüzden hareket ettirilmesi yani çevrilmesi gereken büyüme periyodunun da bu günler içerisinde olması gerekmektedir.

Kuluçka makinesinde geçen büyüme dönemi doğal hayattakinin aksine daha az göz önünde olduğu için yumurtaların gelişim durumu mutlaka kontrol edilmelidir. Bu kontroller periyodik şekilde uygulanmaktadır.

Yumurtanın kuluçka makinesinde gelişmesindeki en büyük faktörlerden birinin ısı olduğu bilinmektedir. Buna bağlı olarak yumurtaların her birine ısının eşit dağılması sağlanmalıdır. Bu da ısının makine içerisinde doğru sirkülasyonunun sağlanması ile belirlenebilmektedir. Kuluçka makinesi içerisinde dağılan sıcaklığın istenilen gelişim için belirli bir seviyede olması gerekmektedir. Kuluçka makineleri için istenilen sıcaklık 36–38 ºC arasında olmak üzere belirlenmiştir.

Kuluçka makinesinde yumurtalarda embriyonik gelişim sağlanabilmesi için doğal habitat taklit edilmektedir. Bu konuda da sıcaklık ve nem oranları kuluçkaya yatan dişinin koşullarına uygun şekilde ayarlanmalıdır. Yumurtaların içerisinde embriyonun gelişimi için yeterli oksijen girişinin olduğundan emin olunmalıdır. Bunun sağlanması için kuluçka makinelerinde oksijen sirkülasyonunu sağlayan fanlar bulunmaktadır. Fanların yeterli sayı da bulunması ve işleyişinde bir aksaklık olmaması mutlaka kontrol edilmelidir.

Tavuk yumurtasındaki embriyonun kuluçka makinesindeki gelişimi için gerekli olarak belirlenen nem oranı % 50 ve % 80 arasında olarak ölçülmüştür.

Kuluçka makinesinin işleyişini sağlayan motor 2- 2,5 d/d devir de çalıştırılarak kullanılmalıdır.

Tablo 1: Kanatlılara göre kuluçka süreleri, ortalama sıcaklık ve nem değerleri

(Anonim, 2025)

	Tavuk	Hindi	Ördek	Kaz	Bıldırcın
Kuluçka Süresi (gün)	21	28	28	28-34[3]	17
Gelişme Dönemi Süresi (gün)	18[2]	25	25	25-31	14-15
Çıkış Süresi (gün)	2-3[2]	3	3	3-4	2-3
Gelişme Sıcaklığı (°C)	37,6	37,4	37,5	37,4-37,8	37,4
Çıkış Sıcaklığı (°C)	37,2	36,9	37,1	37,0[4]	37,2
Gelişme Nem Oranı (%)	50-60	50-60	50-60	50-60	50-60
Çıkış Nem Oranı (%)	70-80	70-80	70-80	70-80	70-80

Günümüzde kullanılan son teknoloji kuluçka makineleri belirli bölümlerden oluşmaktadır. Bu bölümler sırası ile; Çevirme Ünitesi, Sıcaklık Ünitesi, Nem Ünitesi, Havalandırma Ünitesi, Yumurta Sepeti Ünitesi, Kontrol Ünitesinden oluşmaktadır (Çakır ve Çalış, 2007). Kuluçka makinelerinin çalışma prensibi aşağıdaki gibi sıralanmaktadır. Kuluçka süreci başlamadan önce, makinenin temizlenip sterilize edilmesiyle bakteriyel kontaminasyon önlenir (Grimaldi & Grandi, 2005). Su haznesi doldurularak nem seviyesi ayarlanır, yumurtalar dikkatlice yerleştirilir ve sıcaklık ile nem sensörleri kontrol edilir. İlk aşamada sıcaklık genellikle 37.5°C, nem oranı ise %50-55 arasında olacak şekilde ayarlanmaktadır (Hackett & Dilts, 2004). İnkübasyon sırasında, makine sıcaklığı belirli bir noktada tutar ve uygun nem koşulunun oluşmasını sağlar. Otomatik döndürme mekanizması, embriyonun yumurta içinde serbestçe gelişmesi için yumurtaları düzenli olarak döndürür (Smilor, 1987). Son günlerde, döndürme işlemi durdurulur, nem oranı %65–75'e yükseltilir ve sıcaklık sabit tutulur. Bu, embriyonun çıkım pozisyonunu almasını ve yumurta kabuğunu daha kolay kırmasını destekler (Rubenstein, 1966). Civcivler yumurtadan çıktıktan sonra, birkaç saat boyunca makine içinde kuruyup vücut sıcaklıklarını dengelerler. Son olarak, civcivler makineden çıkarılır, sağlık durumları kontrol edilir ve uygun şekilde bakıma alınır (Bayh-Dole

Act, 1980). Fanlar, sıcaklığın her yumurtaya eşit şekilde ulaşmasını sağlarken, nem oranı yumurtaların içindeki sıvının buharlaşmasını kontrol eder.

Öngörülen Gelecek Gelişmeler

Kuluçka makinelerindeki gelecekteki gelişmeler, dijitalleşme ve otomasyon alanındaki ilerlemelerle birlikte daha hassas kontrol sistemlerinin ortaya çıkmasını sağlayabilir. Örneğin, yapay zeka destekli sistemler, sıcaklık, nem ve döndürme sıklığını embriyo gelişim evrelerine göre optimize edebilir (Grimaldi & Grandi, 2005). Ayrıca, sensör teknolojilerindeki yenilikler, her bir yumurtanın bireysel koşullarını izleyerek başarı oranlarını artırabilir (Hackett & Dilts, 2004). Kuluçka sürecine ait tüm verilerin güvenli ve sabit bir şekilde kayıt altına alınması sağlanarak, gıda güvenliği ve izlenebilirlik alanında önemli bir ilerleme kaydedilebilir. (Smilor, 1987). Ayrıca, sürdürülebilirlik odaklı yeni sistemler, enerji tasarruflu ısıtma ve nemlendirme çözümleri ile çevresel etkileri azaltılabilir (Rubenstein, 1966). Gelecekte bu teknolojilerin dijital izleme ve uzaktan kontrol platformlarının geliştirilmesi de mümkün olabilir, bu sayede kullanıcılar kuluçka makinelerini mobil cihazları üzerinden takip edip yönetebilir (Bayh-Dole Act, 1980).

Sonuç

Kuluçka makineleri, kontrollü ortam koşullarında yumurtaların içerisindeki embriyonun gelişimini sağlayarak hayvansal üretimde önemli bir rol oynamaktadır. Eski çağlarda basit yapılarla başlayan bu süreç, bilimsel ve teknolojik ilerlemelerle modern kuluçka makineleri halini almıştır. Bu makineler, sıcaklık, nem, havalandırma ve döndürme gibi faktörleri kontrol edebilme yeteneği sayesinde, kuluçka verimliliğini büyük ölçüde artırmıştır. Kuluçka makinelerinin gelişimi sayesinde üretim verimliliğini artırmasıyla birlikte, aynı süreçte tavuk eti gelişimine de katkı sağlamıştır. Bu sayede üretim daha hızlı ve verimli olmaya başlamıştır. Geliştirilen teknolojik adımlarla birlikte iş gücünün azalmasına karşılık olarak gözlenmesi daha kolay bir hale de getirilmiştir. Yapay zeka ile yapılabilecek yeniliklerin kuluçka sürecinin daha detaylı bir şekilde yönetilmesine ve başarı oranlarının artmasına katkı sağlayabileceği düşünülmektedir.

Sonuç olarak, kuluçka makineleri, gıda üretiminin devamlılığına katkı sağlayan ve hayvan yetiştiriciliği sektörünü geliştiren önemli bir teknolojik gelişme olarak değerlendirilmektedir. Gelecekte gelişen teknoloji ile artan tüketim ihtiyacını karşılamak için daha verimli, gelişmiş ve kullanışlı bir üretim süreci oluşturulacağı ön görülmektedir.

Referanslar

Anonim. (2025). *Sınıf 9.20 Kuluçka Makineleri Deney İlkeleri*. Tarım ve Orman Bakanlığı. https://www.tarimorman.gov.tr/TRGM/Belgeler/DENEY%20RAPOR%20FORMATLARI/DENEY%20%C4%B0LKELER%C4%B0%20TAMAMI/SINIF-%209.20-KULU%C3%87KA%20MAK%C4%B0NALARI%20DENEY%20%C4%B0LKELER%C4%B0.docx

Bayh-Dole Act. (1980). *Public Law 96-517*. U.S. Government Printing Office. https://www.govinfo.gov

Bayh-Dole Act. (1980). *University and Small Business Patent Procedures Act*. Public Law 96-517. https://www.govinfo.gov

Brown, J. (1987). *History of incubation technology*. Cambridge University Press.

Boleli, I. C., Morita, V. S., Matos Jr, J. B., Thimotheo, M., & Almeida, V. R. (2016). Poultry egg incubation: Integrating and optimizing production efficiency. *Brazilian Journal of Poultry Science, 18*(1), 1–16.

Çakır, A., & Çalış, H. (2007). Kuluçka makinesi tasarımı ve yapımı. *Akademik Bilişim'07- IX. Akademik Bilişim Konferansı Bildirileri*, 593. Dumlupınar Üniversitesi. https://www.akademikbilisim.org/konferans_bildirileri_2007

Galbraith, B., McAdam, R., & Cross, S. E. (2021). A historical and future perspective on the evolution of incubators. *IEEE Transactions on Engineering Management, 68*(1), 265. https://doi.org/10.1109/TEM.2020.2996723

Grimaldi, R., & Grandi, A. (2005). Evaluating business incubators and their role in new venture development. *Technovation, 25*(2), 111–121. https://doi.org/10.1016/j.technovation.2003.12.002

Grimaldi, R., & Grandi, S. (2005). An analysis of business incubators and entrepreneurial networks in Italy. *International Journal of Entrepreneurship and Innovation Management, 5*(2), 113–131. https://doi.org/10.1504/IJEIM.2005.007133

Graham, P. (2005). Y Combinator: The seed accelerator model. Cambridge, MA. Retrieved from https://www.ycombinator.com

Hackett, S. M., & Dilts, D. M. (2004). A real options-driven theory of business incubation. *Journal of Technology Transfer, 29*(1), 41–54. https://doi.org/10.1023/B:JOTT.0000013605.83258.40

Hackett, S. M., & Dilts, D. M. (2004). A systematic review of business incubation research. *Journal of Technology Transfer, 29*(1), 55–82. https://doi.org/10.1023/B:JOTT.0000011181.11952.0f

Hsueh, W., & Collins, A. (2019, June 6). Plasma Insulin (LINCO ELISA) v1 (protocols.io.3uegnte). *Protocols.io.* Retrieved September 27, 2020, from https://www.protocols.io

Michael, R. (n.d.). *Digital Library entry.* Retrieved from http://digitallibrary.usc.edu/cdm/ref/collection/p15799coll77/id/360

French, N. A. (1997). Modeling incubation temperature: The effects of incubator design, embryonic development, and egg size. *Poultry Science, 76*(1), 124–133. https://doi.org/10.1093/ps/76.1.124
Rubenstein, A. H. (1966). Editorial: Research-on-research and R&D management. *IEEE Transactions on Engineering Management, 13*(4), 163–165. https://doi.org/10.1109/TEM.1966.6448956
Rubenstein, A. (1966). Editorial: The need for research in engineering management. *IEEE Transactions on Engineering Management, EM-13*(1), 1–3. https://doi.org/10.1109/TEM.1966.6432356
Smilor, R. W. (1987). Commercializing high technology: The commercialization of university research. *Journal of Technology Transfer, 12*(2), 91–106. https://doi.org/10.1007/BF02379123
Smilor, R. W. (1987). Managing the incubator system: Critical success factors to accelerate new company development. *IEEE Transactions on Engineering Management, 34*(3), 146–155. https://doi.org/10.1109/TEM.1987.6498875
Smith, R. (2005). *Ancient agricultural practices in Egypt*. Oxford University Press.
Türkoğlu, M., & Sarıca, M. (2014). Tavukçuluk bilimi: Yetiştirme, besleme, hastalıklar. In *Bölüm 6* (ss. 186–207). Ankara: Nobel Yayın Dağıtım.
Uçar, A., Türkoğlu, M., & Sarıca, M. (2018). Evolution of broilers and broiler breeders. *Turkish Journal of Agriculture Food Science and Technology, 6*(1), 73–77. https://doi.org/10.24925/turjaf.v6i1.73-77.1751
Weele, M. V., Rijnsoever, F. J. V., & Nauta, F. (2017). You can't always get what you want: How entrepreneur's perceived resource needs affect the incubator's assertiveness. *Technovation, 59*, 18–33.
Yaşrin, E., & Sert, T. (2021). Otomatik kuluçka makinası (MM 4006 bitirme projesi). Karadeniz Teknik Üniversitesi, Makina Mühendisliği Bölümü. Proje danışmanı: Dr. Öğr. Üyesi Nurhan Gürsel Özmen. https://www.ktu.edu.tr/dosyalar/makina_d8a51.pdf
Zhang, L. (2010). *Traditional incubation methods in ancient China*. Chinese Academy of Sciences Press.

Horticultural Performance and Functional Quality Traits of Four Hot Pepper Landraces from Tunisia

Marwa Chouikhi[1*], Riadh Ilahy[1], Imen Tlili[1] and Thouraya R'him[1]

[1] Laboratory of Horticulture, National Institute of Agronomic Research of Tunisia, University of Carthage, Hèdi Karray Street, 2049 Ariana, Tunisia.
*Correspondence

ORCIDs:
ing.marwa.chouihki@gmail.com https://orcid.org/0009-0005-3895-4437

bn.riadh@gmail.com https://orcid.org/0000-0001-9405-3098

imen_tlili2008@yahoo.fr https://orcid.org/0000-0002-7132-1915

thouraya.rhim@yahoo.fr https://orcid.org/0000-0001-5912-9982

Abstract

Worldwide pepper (*Capsicum annuum* L.) is considered one of the most important vegetable crops grown and consumed. We have comprehensively assessed the horticultural performance and the functional quality traits of four hot pepper genotypes adapted to various climatic conditions in Tunisia comprising of 'Semmane' 'Jerid', 'Mahdia' and 'Kairouan'. Most of the pepper genotypes showed satisfactory yields ranging from 1163.25 to 1841.67 g plant^{-1} in 'Jerid' and 'Kairouan' respectively underlying a good productivity particularly under the ongoing climatic changes and high temperature. Capsaicinoids, carotenoids and tocopherols contents varied significantly among the studied pepper genotypes ($P \leq 0.05$). Capsaicinoids content ranged from 1.81 µg g^{-1} FW in 'Kairouan' to 193.71 µg g^{-1} FW in 'Jerid'. 'Semmane' exhibited the highest value of carotenoids content (174.52 µg g^{-1} FW). Finally, the highest tocopherols content was recorded to 'Jerid' (31.24 µg g^{-1} FW). Although other traits were not considered in this study, the hot pepper genotype 'Semmane' exhibited the highest value of carotenoids content and might be suitable to grow for fresh and/or processing purposes or to be considered as starting point for future breeding programs targeting the development of new cultivars for the next decade.

Keywords: *Pepper, horticultural performances, physiological attributs and functional quality.*

Introduction

Peppers (*Capsicum annuum* L.) are among the most important crops plants included in the Solanaceae family. They are one of the most widely consumed vegetables throughout the world with a production attaining 36.77 million tons in the world and 425000 tons. In Tunisia owing to their attractive colours and strong flavour. Pepper fruits have been recognized as natural sources of various bioactive compounds (Duah et al., 2021). It has been reported that the levels of these compounds vary depending on various factors such as genotypic differences, pre- and post-harvest agricultural practices (Diaz-Sanchez et al., 2021; Moon al., 2023). Therefore, this study targeted to assess the horticultural performance and the functional quality attributes of four hot pepper landraces grown under open field conditions.

Materials and Methods

The field-experiment was conducted during 2022 growing season at the Research and Experimental Station of Teboulba, Monastir, Tunisia (35.637178, 10.957276). Four pepper genotypes were used in this experiment consisting of Semmane, Jerid, Kairouan and Kairouan. Sowing was carried out in plug-seedling trays during May. Pepper seedlings were transplanted in open-field in a sandy soil at the beginning of June with a spacing of approximately 0.4 m within the row and 0.7 m between rows, matching a density of about 4 plants.m^{-2} and grown until maturity. Drip irrigation was applied during 1-3 h at different days intervals in agreement with the local evapotranspiration potential, climatic conditions, crop coefficient and growth stage. The growing calendar was also in accordance with the techniques used by the Research station and high-yielding neighbouring farmers. The method included the use of synthetic chemical fertilizers (145 kg N ha^{-1}, 140 kg P_2O_5 ha^{-1}, 210 kg K_2O ha^{-1}). Chemical fertilizer solution was added to water irrigation by pump injection twice a week. The production method also consists of hand weeding and plant-pathogen control with synthetic chemical pesticides. Pesticides were applied once a cycle. The experimental design was a randomized complete block design with three blocks (replicates). During 2022 growing season, the average temperature ranged between 24.88-33°C, relative humidity ranged between 55-88% and rainfall ranged between 0-5 mm. Photosynthesis and leaf transpiration were measured in single pepper leaves using a portable photosynthesis system model (CI-301 CO_2 Gaz analyser (CID Inc, Camas, WA, USA), and this measurement was conducted one hour after sunrise and stomatal conductance was measured using promoter (DELTA- T AP4). Photosynthesis, transpiration and stomatal conductance were expressed as µmol m^{-2} s^{-1}. Plant height was measured at the end of the experiment. It was taken from the root collar to the highest point of the plant. The yield was evaluated considering the weight of fruits per plant. Plant yield was expressed as grams of fresh weight $plant^{-1}$. Regarding average fruit weight, a random sample of pepper fruits was used and average fruit weight was deduced by dividing the weight of the sample by the number of the fruit within the sample. Average fruit weight was expressed in gram of fresh weight.

Fruit sampling

Peppers were collected from each plant at the commercial red mature ripening stage. Fresh pepper fruits were harvested from each bloc and delivered to the laboratory. The selected pepper fruits were washed with deionized water, cut into small pieces and homogenized in a laboratory blender (Waring Laboratory Science, Torrington, CT, US). The obtained homogenates were used to assess capsaicinoids, carotenoids and tocopherols.

Determination of capsaicinoid content

Using the techniques of Daood et al. (2014). In a crucible mortar, three grams of pepper homogenate were crushed with quartz sand. After carefully pouring 50 mL of analytical grade methanol, the liquid was placed into a 100 mL Erlenmeyer flask fitted with a stopper. After three minutes of ultrasonication, the mixture was filtered through filter paper. The filtrate was then filtered using a 0.22 µm PTFE (Chromfilter) syringe into vails after being diluted ten times (9:1) using 9 mL of chromatography grade methanol and 1 mL of filtrate from different pepper landraces. The filtrate was then filtered through a 25 µm syringe and placed into a 10 mL glass beaker. Using an Eppendorf pipette, 1 mL of methanol and 1 mL of the filtrate (from the syringe filter) were further diluted into vails. Total capsaicinoid content was expressed as mg kg^{-1} FW.

Determination of carotenoid content

Total carotenoids were determined according to the protocols of Daood et al. (2014). About 2.5 g of homogenized pepper samples from different landraces were crushed in a crucible mortar with quartz sand. A volume of 20 mL of methanol was added for 1-2 min, and the upper layer poured into an Erlenmeyer flask. 10 mL of methanol (analytical grade) was then added to 50 mL of dichloroethane in a 100 mL graduated cylinder and shaken gently. The mixture was poured into the remaining homogenized pepper sample in the crucible mortar and then transferred into the Erlenmeyer flask and shaken vigorously. A few drops of distilled water were added and shaken gently and the mixture was separated with a burette into a flat bottom flask using a filter paper containing sodium sulfate anhydrous in a separating funnel. 5 mL of dichloroethane was added to the filtrate through a filter paper for further extraction and evaporated using a rotary evaporation chamber during 10 min at 70 ◦C and 40 ◦C vacuum, respectively. The flask was offloaded from the chamber tube after all filtrate evaporated. 5 mL of pigment eluents and 5 mL of analytical grade methanol were respectively dropped into the flask and shaken evenly and an ultrasonic shaker was used where necessary to ensure that no residue was left in the flask. Then the solution was filtered through a 0.22 µm PTFE membrane syringe into the veils and injected into the HPLC column. An HPLC (Hitachi Chromaster, Tokyo, Japan) instrument consisting of a Model 5110 Pump, a Model 5210 Auto Sampler, a Model 5430 Diode Array detector, and a Model 5440 FL detector, was used for the determination of all compounds. All chemicals, including analytical and HPLC grade solvents, were obtained from VWR (Budapest, Hungary, and Darmstadt, Germany). Total carotenoids content was expressed as mg kg^{-1} FW.

Determination of Tocopherol Content

The procedure of Abushita et al. (1997) was adopted for the extraction of tocopherol using n-hexane. The analysis was conducted by the mean of an HPLC (Hitachi Chromaster, Tokyo, Japan). The system was composed of a model 5110 gradient pump, a model 5210 autosampler, and a 5440-fluorescence detector. The Nucleosil 5 mm (250 × 4.6 mm i.d.) column was also used for separation with a mobile phase (99.5:0.5 n-hexane: ethanol). The excitation and emission wavelengths were detected at 295 nm and 320 nm, respectively, as outlined in Duah et al. (2021). Total tocopherol content was expressed as mg kg^{-1} FW.

Statistical Analysis

The variability influencing horticultural performance and functional quality traits of hot pepper landraces were determined by variance (ANOVA) analysis. The means comparison was performed by the Duncan test ($p < 0.05$) if significant differences were spotted. The statistical evaluations were conducted using the IBM SPSS Statistics software for Windows, Version 21.0. (IBM Corp., Armonk, NY, USA).

Results and Discussion

Plant height, yield, average fruit weight

The obtained values of plant height, yield and average fruit weight plant of four pepper genotypes are displayed in Table 1. The result showed a significant difference between pepper genotypes. The plant height varied from 79 cm in 'Semmane' to 115.33 cm in 'Mahdia'. Generally, the assessed plant material showed different vegetative behavior with respect to temperature. This result was statistically confirmed by the analysis of variance which revealed a highly significant effect depending on the genotype. Mahdia is likely more adapted to high temperature unlike Semmane. The differences among pepper genotypes are probably due to their genetic make-up. Plant height is often used as an indicator of plant vigor, but it generally depends on the plant's growth habit. Soil nutrients are also very important for the height of plants (Mohammed Houssein et al., 2012). Yield varied significantly among the studied pepper genotypes ($P < 0.05$). The highest yield 1841.66 g plant^{-1} was obtained by 'Kairouan' and the lowest 1163.25 g plant^{-1} was obtained by 'Jerid'. Pepper genotypes show significant variations in yield plant^{-1} and these variations were presumably correlated to genetic variations (Jan et al., 2020). Genefianti et al. (2008) reported that total yield of the crop was directly proportional to number of fruits per plant. Fitriani et al. (2013) outlined that total yield of different chilli varieties was controlled by environmental conditions greater than genetic attributes. All genotypes showed satisfying yields underlying a good productivity under the ongoing climatic changes and high temperature particularly applying for open-field grown crops during this particular period of time. The average fruit weight ranged from 6.5 g in 'Jerid' to 37.75 g in 'Kairouan'. 'Semmane' and 'Mahdia' showed average fruit weight generally appreciated by fresh market consumers. Ilić et al. (2017) assessed old traditional Serbian pepper landraces (Nizača, Lokošnička and Turšijara), grown in South Serbia and reported variations in fruit weight ranging from 46 g in Nizaca to 60 g in Tursijara. The investigated pepper genotypes exhibited acceptable agronomic traits. Pepper genotypes showed significant variations in yield and these variations are generally controlled by the environmental conditions greater than genetic attributes (Miller and Rice-Evans, 1997; Fitriani et al., 2013).

Table 1. Agronomic attributes of pepper genotypes grown under open-field.

Genotypes	Plant height (cm)	Yield (g)	Average fruit weight (g)
Semmane	79±1.67b	1687.25±40b	34.33±1.11a
Jerid	85.67±4.44b	1163.25±47.17c	6.5±0.5b
Mahdia	115.33±1.78a	1634.92±22.55b	33.83±0.39a
Kairouan	87.33±1.78b	1841.67±17.94a	37.75±0.17a

Physiological traits

Photosynthesis, transpiration and stomatal conductance of four pepper genotypes are shown in Table 2. The results show significant differences between the varieties, indicating variability in their physiological response to growing conditions. Photosynthesis revealed that 'Kairouan' recorded the highest intensity with 14,88 µmol m^{-2} s^{-1}, followed by 'Mahdia'. These varieties, with their high photosynthetic activity, were found to be the most efficient in terms of light utilization and CO_2 conversion into energy, giving them an higher performances in terms of growth and yield under favorable conditions (R'him et al., 2005). The lowest photosynthesis activity was detected in 'Jerid' (12.29 µmol m^{-2} s^{-1}). 'Jerid' could have a reduced capacity for light capture, probably due to the reduced size of leaves and stomata (R'him, 2005). Regarding transpiration, 'Semmane' displayed the highest transpiration rate (3.96 µmol m^{-2} s^{-1}), these genotype with high rate, signaling a more intense environmental interaction and therefore an increased water loss by evaporation, which could make them more sensitive to water stress in dry periods. Conversely, 'Jerid' with lower transpiration rate, seem to better conserve water, indicating a better adaptation to arid environments, where reducing water loss is crucial. This is consistent with the origin of these varieties and their adaptability, as reported previously by R'him et al. (2008, 2010). In terms of stomatal conductance, 'Mahdia' recorded the highest value (402.67 µmol m^{-2} s^{-1}), followed by Kairouan and Semmane. On the other hand, 'Jerid' displayed the lowest stomatal conductance (285.33 µmol m^{-2} s^{-1}). This low conductance, coupled with limited transpiration, could be due to the small size of its stomata (R'him, 2005), which makes this variety less reactive to environmental variations compared to the other varieties studied.

Table 2. Photosynthesis, transpiration and stomatal conductance of four pepper genotypes grown in Tunisia.

Genotypes	Photosynthesis (µmol m^{-2} s^{-1})	Transpiration (µmol m^{-2} s^{-1})	Stomatal conductance (µmol m^{-2} s^{-1})
Semmane	13.79±0.36 b	3.96±0.09 a	367±28 b
Jerid	12.29±0.3 c	3.13±0.02 c	285.33±11.78 c

Mahdia	14.48±0.56 a	3.6±0.32 b	402.67±6.22 a
Kairouan	14.88±0.09 a	3.68±0.35 b	363.33±20.44 b

Functional quality traits

Capsaicinoids, carotenoids and tocopherols contents of the studied pepper genotypes are reported in table 3. Capsaicinoids content varied significantly among the studied pepper genotypes ($P \leq 0.05$). The highest value (193.71 µg g^{-1} FW) was recorded in 'Jerid', while the lowest (1.81 µg g^{-1} FW) was recorded in cultivar 'Kairouan'. Capsaicinoid content is strongly influenced by genetic traits (Jeeatid et al., 2018). Our results are in agreement with various authors (Alam et al., 2020; Castillo-Aguilar et al., 2021; Diaz-Sanchez et al., 2021; Moon al., 2023; Diaz-Sanchez et al., 2021). However, differences compared to previously published data, would be explained by the fact that capsaicinoid synthesis does not only depend on the variety but also on the growing conditions. Indeed, the variation in temperatures and relative humidity during fruit development (from fruit set to maturity) also contributes to the variation in capsaicinoid contents (Garcès-Claver et al., 2007; Rahmen and Inden, 2012). It has been reported that the amount of capsaicinoids is highly variable in pepper, depending strongly on the variety, but also on many parameters such as the stage of maturity, the growing season and irrigation (Reyes-Escogido et al., 2011). Total carotenoids showed large variability among the tested pepper landraces and ranged from 45.94 µg g^{-1} FW in 'Kairouan' to 174.52 µg g^{-1} FW in 'Semmane'. Our results were similar with the conclusions of several other studies (Maiani et al. (2009); Rodríguez et al. (2020); Da Silveira et al. (2016) Martínez-Ispizua et al. (2021) and Moon et al. (2023)), highlighting the importance of genetic characteristics in determining carotenoid content in pepper varieties. The observed variation among the different studied varieties is primarily attributed to the varietal effect. Also, the effect of the environment under which the fruit was formed (Wall et al., 2001) could have an impact mainly temperature (Russo and Howard, 2002), light (Doumandji et al 2012) and even cold (Markus et al, 1999). Da Silveira et al. (2016) reported large variability among pepper landraces regarding total carotenoids content confirmed the influence of genotypic make-up on this particular trait. Tocopherols content ranged from 19.38 µg g^{-1} FW in 'Kairouan' to 31.24 µg g^{-1} FW in 'Jerid'. Tocopherols content is probably affected by lipid content, which varies with variety and stage of maturity (Kanner et al., 1979; Jorge et al., 1998).

Table 3. Functional quality traits of four pepper genotypes grown in Tunisia.

Genotypes	Capsaicinoids (µg g^{-1} FW)	Carotenoids (µg g^{-1} FW)	Tocopherols (µg g^{-1} FW)
Semmane	36.65±0.32b	174.52±21.09a	23.32±1.92b
Jerid	193.71±1.32a	147.40±12.70a	31.24±5.21a
Mahdia	3.01±0.09c	64.33±10.16b	19.85±0.86b
Kairouan	1.81±0.19c	45.94±5.97b	19.38±0.3b

Conclusion

The study provides a clear insight not only into horticultural performances but also into the functional quality of different pepper genotypes. The study also showed that most of the genotypes are cumulating useful agronomic, physiological and functional quality traits suitable to be exploited for further breeding programs and selections process aiming to develop high-yielding genotypes with minimal requirement (inputs and water) particularly under the ongoing climatic changes worldwide.

Acknowledgements

The authors would like to acknowledge Professor Mohamed Rabeh Hajlaoui from National Agricultural Research Institute for laboratory facilities and her technical assistance.

References

Abushita AA, Hebshi EA, Daood HG, Biacs PA. Determination of antioxidant vitamins in tomatoes. *Food Chem.* (1997) 60:207– 12. https://doi.org/10.1016/S0308-8146(96)00321-4

Alam, M. A., Saleh, M., Mohsin, G. M., Nadirah, T. A., Aslani, F., Rahman, M. M., & Alam, M. Z. (2020). Evaluation of phenolics, capsaicinoids, antioxidant properties, and major macro-micro minerals of some hot and sweet peppers and ginger landraces of Malaysia. *Journal of food processing and preservation*, *44*(6), e14483. https://doi.org/10.1111/jfpp.14483

Castillo-Aguilar, C. C., Castilla, L. L., Pacheco, N., Cuevas-Bernardino, J. C., Garruña, R., & Andueza-Noh, R. H. (2021). Phenotypic diversity and capsaicinoid content of chilli pepper landraces (Capsicum spp.) from the Yucatan Peninsula. *Plant Genetic Resources*, *19*(2), 159-166. https://doi.org/10.1017/S1479262121000204

Daood HG, Bencze G, Palotas G, Pék, Z, Sidikov A, et al. HPLC analysis of carotenoids from tomatoes using cross-linked C18 column and MS detection. *J Chromatogr Sci*. (2014) 52:985–91. https://doi.org/10.1093/chromsci/bmt139

Da Silveira Agostini-Costa, Tania., da Silva Gomes, Ismael., de Melo, Luis Alberto Martins Palhares., Reifschneider, Francisco Jose Becker., & da Costa Ribeiro, Claudia Silva.(2017). Carotenoid and total vitamin C content of ´ peppers from selected Brazilian cultivars. *Journal of Food Composition and Analysis*, 57, 73-79. https://doi.org/10.1016/j.jfca.2016.12.020

Díaz-Sánchez, D. D., López-Sánchez, H., Silva-Rojas, H. V., Gardea-Béjar, A. A., Cruz-Huerta, N., Ramírez-Ramírez, I., & González-Hernández, V. A. (2021). Pungency and fruit quality in Mexican landraces of piquín pepper (Capsicum annuum var. glabriusculum) as affected by plant growth environment and postharvest handling. *Chilean journal of agricultural research*, *81*(4), 546-556. http://dx.doi.org/10.4067/S0718-58392021000400546

Doumandji, A., Boutekrabt, L., Saidi, N. A., Doumandji, S., Hamerouch, D., & Haouari, S. (2012). Etude de l'impact de l'incorporation de la spiruline sur les propriétés nutritionnelles, technologiques et organoleptiques du couscous artisanal. *Revue «Nature & Technologie». n*, *6*, 41.

Duah, S.A., Souza, C.S., Daood, H.G., Pék, Z., Neményi, A., & Helyes, L.(2021). Content and response to Ɣ-irradiation before over-ripening of capsaicinoid, carotenoid, and tocopherol in new hybrids of spice chili peppers. *Food Science and Technology*, 147, 111-555. https://doi.org/10.1016/j.lwt.2021.111555

Fitriani, L., Toekidjo and S. Purwanti. 2013. The performance of five cultivated varieties of pepper (Capsicum annum L.) at the middle land. *Vegetalika*. 2(2): 50-63.

Garcés-Claver, A., Gil-Ortega, R., Álvarez-Fernández, A., & Arnedo-Andrés, M. S. (2007). Inheritance of capsaicin and dihydrocapsaicin, determined by HPLC-ESI/MS, in an intraspecific cross of Capsicum annuum L. *Journal of Agricultural and Food Chemistry*, *55*(17), 6951-6957. https://doi.org/10.1021/jf070951x

Genefianti, D.W., S. Sujiprihati, S.H. Hidayat and M. Syukur. 2008. Metode penularan dan uji ketahanan genotipe cabai (Capsicum spp.) terhadap begomovirus. *J. Akta Agrosia*. 11(2): 162-169. https://doi.org/10.21082/jhort.v25n3.2015.p246-256

Ilić, Z. S., Kevrešan, Ž., Mastilović, J., Zorić, L., Tomšik, A., Belović, M., & Luković, J. (2017). Evaluation of Mineral Profile, Texture, Sensory and Structural Characteristics of Old Pepper Landraces. *Journal of food processing and preservation*, *41*(5), e13141. https://doi.org/10.1111/jfpp.13141

Jan, J.A., G. Nabi, M. Khan, S. Ahmad, P.S. Shah, S. Hussain and Sehrish. 2020. Foliar application of humic acid improves growth and yield of chilli (Capsicum annum L.) varieties. *Pakistan Journal of Agricultural Research*, 33(3): 461-472. https://doi.org/10.17582/journal.pjar/2020/33.3.461.472

Jeeatid, N., Suriharn, B., Techawongstien, S., Chanthai, S., Bosland, P. W., & Techawongstien, S. (2018). Evaluation of the effect of genotype-by-environment interaction on capsaicinoid production in hot pepper hybrids (Capsicum chinense Jacq.) under controlled environment. *Scientia horticulturae*, *235*, 334-339.

https://doi.org/10.1016/j.scienta.2018.03.022

Jorge A. Osuna-Garcia, Marisa M. Wall and Cynthia A. Waddell. (1998). Endogenous Levels of Tocopherols and Ascorbic Acid during Fruit Ripening of New Mexican-Type Chile (Capsicum annuum L.) Cultivars. *J. Agric. Food Chem*. 46, 5093−5096. https://doi.org/10.1021/jf980588h

Kanner, J.; Harel, S.; Mendel, H. (1979). Content and stability of R-tocopherol in fresh and dehydrated pepper fruits (*Capsicum annuum L.*). *J. Agric. Food Chem*. 27, 1316- 1318. https://doi.org/10.1021/jf60226a057

Maiani G, Castón MJ, Catasta G, Toti E, Cambrodón IG, Bysted A, et al. (2009). Carotenoids: actual knowledge on food sources, intakes, stability and bioavailability and their protective role in humans. *Molecular Nutrition & Food Research*, 53, S194–218. https://doi.org/10.1002/mnfr.200800053

Martínez-Ispizua, E., Martínez-Cuenca, M. R., Marsal, J. I., Díez, M. J., Soler, S., Valcárcel, J. V., & Calatayud, Á. (2021). Bioactive compounds and antioxidant capacity of valencian pepper landraces. *Molecules*, *26*(4), 1031. https://doi.org/10.3390/molecules26041031

Markus, F., Daood, H. G., Kapitany, J., & Biacs, P. A. (1999). Change in the carotenoid and antioxidant content of spice red pepper (paprika) as a function of ripening and some technological factors. *Journal of agricultural and food chemistry*, *47*(1), 100-107. https://doi.org/10.1021/jf980485z

Miller NJ, Rice-Evans CA. (1997). Factors influencing the antioxidant activity determined by the ABTS•+ radical cation assay. Free Radic Res. 26:195–9. https://doi.org/10.3109/10715769709097799

Mohammed Houssein A, Houssein A, Atefe A and Hamide F., 2012. Effect of plant density and nitrogen fertilizer on growth, yield and fruit quality of sweet pepper (Capsicum annum L.). *African Journal of Agricultural Research Vol.* 7(6), pp. 859-866. Available online at https://doi.org/10.5897/AJAR2025.16860 .

Moon, S., Ro, N., Kim, J., Ko, H. C., Lee, S., Oh, H., & Lee, G. A. (2023). Characterization of diverse pepper (*Capsicum spp.*) germplasms based on agro-morphological traits and phytochemical contents. *Agronomy*, *13*(10), 2665. https://doi.org/10.3390/agronomy13102665

Rahman, M. J., & Inden, H. (2012). Effect of nutrient solution and temperature on capsaicin content and yield contributing characteristics in six sweet pepper (*Capsicum annuum L.*) cultivars. http://www.isfae.org/scientificjournal.php

Reyes-Escogido, M. D. L., Gonzalez-Mondragon, E. G., & Vazquez-Tzompantzi, E. (2011). Chemical and pharmacological aspects of capsaicin. *Molecules*, *16*(2), 1253-1270. https://doi.org/10.3390/molecules16021253

R'him, T. et Jebari, H. (2005). Effet de différents taux d'humidité de l'air sur les échanges gazeux chez quatre variétés Tunisiennes de piment (*Capsicum annuum L.*). Ann. Inst.Nat. de la Rech. Agron de Tunisie, 78, 45-58.

R'him, T., & Jebari, H. (2008). Blossom-end rot in relation to morphological parameters and calcium content in fruits of four pepper varieties (*Capsicum annuum L.*). http://www.bib.fsagx.ac.be/base/

R'him, T., Tlili, I., Ilahy, R., da Silva, J. A. T., & Hamza, N. (2010). The Effect of growing season and culture media on another culture response of some pepper cultivars (*Capsicum annuum L.*) Grown in Tunisia. *The African Journal of Plant Science and Biotechnology*, *4*, 81-84.

Rodríguez-Rodríguez, E., Sánchez-Prieto, M., Olmedilla-Alonso, B. (2020). Assessment of carotenoid concentrations in red peppers (Capsicum annuum) under domestic refrigeration for three weeks as determined by HPLC-DAD, *Food Chemistry,* https://doi.org/10.1016/j.fochx.2020.100092

Russo, V. M., & Howard, L. R. (2002). Carotenoids in pungent and non-pungent peppers at various developmental stages grown in the field and glasshouse. *Journal of the Science of Food and Agriculture*, *82*(6), 615-624. https://doi.org/10.1002/jsfa.1099

Wall, M. M., Waddell, C. A., & Bosland, P. W. (2001). Variation in β-carotene and total carotenoid content in fruits of Capsicum. *HortScience*, *36*(4), 746-749.

Food Safety Knowledge, Attitude, and Practices Among Employees: A Case Study at Food Court of Kandy City Centre, Sri Lanka.

S.A.A.K. Abeywickrama 1, R.A.G.U. Ranasinghe 2

[1] Department of Food Science and Technology, Faculty of Livestock, Fisheries and Nutrition, Wayamba University of Sri Lanka, Makandura, Gonawila (NWP)
2 School of Public Administration, University of Electronic Science and Technology of China.

Abstract
Improper food handling is a major cause of food contamination, which can pose serious health risks. To prevent such contamination, food handlers must possess adequate knowledge, demonstrate a positive attitude, and consistently practice proper food handling techniques. This study aimed to evaluate the food safety knowledge, attitudes, and practices of employees working in the food court of Kandy City Centre, as well as to identify the factors influencing these aspects. Data were collected from 50 food handlers involved in the preparation, serving, and sale of readymade food between June 2023 and September 2023. A questionnaire was used to gather information on socio-demographic variables, food safety knowledge, attitudes, and practices through interviews. The majority of respondents (61.5%) were under 25 years of age, and 75% were male. Almost all food handlers were aware of critical sanitary practices, such as personal hygiene (100%) and hand washing (98%). The study found that most participants (90.4%) had received basic food safety training, and 84.6% had undergone Hazard Analysis Critical Control Point (HACCP) training. The average percentages for food safety knowledge, attitudes, and practices were 77%, 82.2%, and 87%, respectively. While the study showed that food handlers generally have satisfactory knowledge, attitudes, and practices regarding food safety, some areas, particularly cross-contamination and time/temperature control, require further emphasis. The study recommends continuous food safety training to reinforce the weaker areas, with a focus not only on theoretical knowledge but also on practical skills and the promotion of positive attitudes towards food safety.
Key Words: *Food Handling, Cross-Contamination, Hazard Analysis Critical Control Point, Training, Practical Skills*

Introduction
Food safety and foodborne diseases are globally recognized public health concerns that are closely interlinked. Every year, thousands of people suffer from foodborne illnesses, and many succumb to the consumption of food contaminated with biological, chemical, or physical hazards (Azanaw et al., 2021; Tewari & Abdullah, 2015). Foodborne disease outbreaks continue to be a major public health issue worldwide, exacerbated by factors such as mass-scale food production and distribution, the expansion of global food supply chains, and the growing consumption of ready-to-eat food from street vendors and (King et al., 2017; Nyachuba, 2010; Quested et al., 2010). The emergence of new foodborne pathogens further complicates efforts to curb foodborne diseases.
Governments around the world have strengthened their efforts to improve food safety standards and combat the rising number of foodborne illnesses. Populations at higher risk, including infants, young children, immunocompromised individuals, pregnant women, and the elderly, are especially vulnerable to severe health complications from unsafe food (Kendall et al., 2003). Among these, malnourished children and infants are particularly susceptible, with foodborne diarrheal diseases contributing to over one billion cases of diarrhea annually among children, resulting in more than three million deaths worldwide (World Health Organization, 2020). According to the WHO, foodborne diseases affect one in ten people globally each year. In the South-East Asia Region alone, there are an estimated 150 million illnesses, 175,000 deaths, and 12 million disability-adjusted life years (DALYs) due to foodborne diseases.
To mitigate the risks associated with foodborne illnesses, it is crucial to ensure the implementation of effective food safety standards. These standards must integrate both safety and quality throughout the food production and service processes (Van der Meer, 2015). Commercial food outlets, including food courts, play a significant role in reducing foodborne illness risks by adhering to hygiene protocols and food safety regulations. In this context, food courts and similar establishments often follow internationally recognized standards, such as ISO 22000:2018 Food Safety Management System and Hazard Analysis and Critical Control Points (HACCP), to ensure food safety, quality, and compliance with regulatory requirements (ISO, 2018). However, despite the existence of food safety regulations and training programs, there is a gap in research concerning the actual food safety knowledge, attitudes, and practices of food handlers in urban food courts in Sri Lanka. Most existing studies on food safety in Sri Lanka have focused on street vendors and small-scale food establishments (Khan et al., 2016), with limited attention given to larger, structured food service outlets that operate under internationally recognized food safety standards, such as ISO 22000:2018 and HACCP (Gaur & Singhal, 2015; López-Gálvez et al., 2018) . Understanding the level of food safety knowledge and practices among food handlers in such settings is essential for evaluating the effectiveness of food safety training programs and identifying areas where further interventions are necessary.

Therefore, present study aims to assess the food safety knowledge, attitudes, and practices of employees working in a selected commercial food outlet and explore the factors influencing them. We selected the food court of Kandy City Centre for our study due to its relevance. A structured, pre-tested questionnaire was used to collect data from selected employees engaged in food preparation, serving, and sales. The outcomes of this study will provide valuable insights into the gaps in food safety compliance, the effectiveness of existing training programs, and practical measures that can be taken to enhance food safety practices. Ultimately, the study seeks to contribute to improving food safety standards, reducing the risk of foodborne illness, and ensuring safer food practices in commercial food courts across Sri Lanka.

Materials and Methods

Research Design

A descriptive research design was employed to evaluate the food safety knowledge, attitudes, and practices of food handlers working at the Kandy City Centre food court. A cross-sectional study design was adopted, where data were collected from a sample of food handlers at a specific period of time (from June 2023 to September 2023). The study was primarily quantitative in nature, as the aim was to measure variables related to food safety knowledge, attitudes, and practices.

Sample Size

50 were randomly selected from 109 of food handlers engaged in food preparation, serving, and sales in the food court of Kandy City Centre. The composition of the sample was based on key demographic and work-related factors, including age, gender, educational level, and work responsibility.

Data Collection

The data collection tool for this study was a structured questionnaire, which was developed to assess the knowledge, attitudes, and self-reported practices of food handlers related to food safety. The questionnaire was developed following the principles from Hazard Analysis and Critical Control Points (HACCP), as well as elements assessed in previous studies (McIntyre et al., 2013; Rebouças et al., 2016; Sharif & Al-Malki, 2010) and Zimbabwe's food safety legislation (Ministry of Health and Child Care, 1996a, 1996b). The questionnaire was designed in English and consisted of five sections::

1. Demographic Information: Age, gender, educational level, work responsibilities.
2. Work History: Details regarding the participants' professional experience and food handling roles.
3. Food Safety Knowledge: 17 items assessing knowledge related to food spoilage, storage, contamination, and foodborne illnesses.
4. Food Safety Attitudes: 14 items focusing on food handlers' perceptions of food safety training, hygiene practices, and contamination prevention.
5. Self-Reported Practices: 21 items on food handling, sanitation, and temperature control practices.

Pre-test and Validation

The questionnaire was peer-reviewed by two professional food inspectors and was piloted with 25 respondents (24.8% of the sample size). Feedback from the pre-test led to revisions in the questionnaire to improve clarity and ensure that the questions were culturally appropriate and comprehensible. The revised version was then used for data collection.

Administration of the Questionnaire

The questionnaires were self-administered by the respondents in the presence of trained research assistants to ensure that they could not seek help from their colleagues or reference materials. In cases where respondents were unable to read or write, trained research assistants conducted the interview and completed the questionnaire for the participant. Before administering the questionnaire, participants were given a 10–15-minute orientation to explain the study's objectives, their rights, and the importance of providing accurate and complete information. The confidentiality of responses was emphasized to minimize bias, and participants were assured that their individual responses would not be shared with management.

Ethical Considerations

Prior to data collection, ethical approval for the study was obtained from the relevant institutional review board. All participants were informed about the study's objectives, their rights, and the voluntary nature of their participation. To ensure anonymity and confidentiality, participants were instructed not to include any personal identifying information on the questionnaires. Data were stored securely, and only aggregated data were analyzed and reported to prevent identification of individual respondents.

Data Analysis

Data collected from the questionnaires were analyzed using descriptive statistical methods to summarize the responses. The analysis included the following:

1. Percentage Analysis: The responses for food safety knowledge, attitudes, and practices were calculated as percentages to determine the distribution of correct or positive responses.
2. Frequency Distribution: The frequencies of each response across various questions were calculated to identify common trends and patterns in food safety knowledge and behavior.
3. Graphical Representation: The results were presented using bar graphs and pie charts to visually represent the distribution of responses across different variables (e.g., knowledge of hygiene practices, attitudes toward food safety, and adherence to sanitation protocols).

The data were summarized in tables and graphs to clearly present the distribution of food handlers' knowledge, attitudes, and practices concerning food safety.

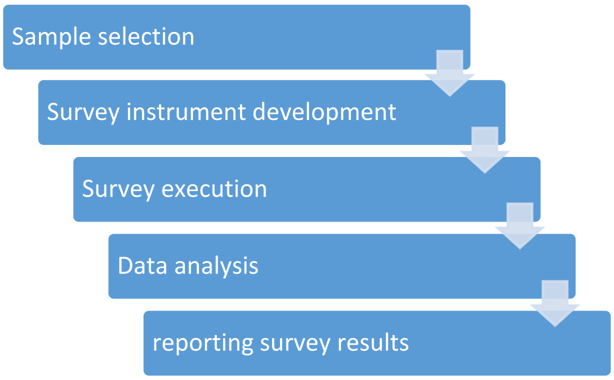


Figure 1: Methodology

Results and Discussion

Association of socio-demographic characteristics with food safety knowledge and attitudes

Results on the association between socio-demographic characteristics and food safety knowledge and attitudes are presented in Table 1. As shown, the present study found no significant differences in food safety knowledge and attitudes based on gender, age, educational level, or work experience, consistent with findings from Malaysia (Abdul-Mutalib et al., 2012). However, other research has shown that factors such as work experience and educational level were significantly associated with improved food safety knowledge in the United States (McIntyre et al., 2013). These contrasting findings can be attributed to differences in the study populations, food safety training programs, or regional food safety regulations. Specifically, McIntyre et al.'s study was conducted in a context where food safety training was more accessible or mandated, which explains the observed correlation with higher knowledge scores. The majority of participants in the current study (61.5%) were males under 25 years. This suggests that the workforce in this setting may lack the diversity in food handling experience, potentially increasing the risk of food contamination due to non-adherence to good manufacturing practices. The absence of significant associations between these demographic factors and food safety knowledge could be attributed to the relatively homogenous demographic profile of the participants in the current study. Additionally, younger workers may be more likely to follow standardized practices, as these practices are often a central part of their training and employment in such environments.

Regarding educational background, about 3.8% of food handlers had not gone beyond primary education. This highlights the importance of food safety training in improving food handlers' knowledge. The findings indicate that those who had received basic food safety training exhibited significantly higher knowledge scores compared to those who had not, which aligns with previous conclusions (McIntyre et al., 2013). In this study, a large proportion of food handlers (90.4%) had received basic food safety training, and 84.6% had received HACCP training. This suggests that structured training programs play a crucial role in improving food safety knowledge and attitudes, even though the influence of socio-demographic factors such as age and education remained minimal. To further clarify, future research should explore whether socio-demographic factors, such as age or educational level, influence actual food safety practices rather than just knowledge and attitudes. The focus on training and its potential impact on reducing foodborne risks could also be expanded, particularly by assessing the practical application of food safety standards in the workplace.

Table 1 Comparison between Attitudes and food safety practices

Variable	%	Food safety knowledge		Food safety practice	
		Satisfactory(%)	Inadequate(%)	Negative(%)	Positive(%)
Gender					
Male	75	31	8	5	34
Female	25	10	3	2	11
Age					
<= 25	61.5	21	9	6	24
>25	38.5	18	2	1	19
Educational level					
Primary and below	3.8	0	2	1	1
Secondary and above	96.2	39	9	6	42
Work Experience					
<=2	19.2	6	6	0	12
>2	80.8	33	5	7	31
Basic Training on Food safety					
Trained	90.4	37	6	1	42
Not Trained	9.6	2	5	6	1
HACCP trained					
Trained	84.6	36	4	1	39
Not Trained	15.4	3	7	6	4

Knowledge of participants on food safety

Food safety knowledge among participants showed in the table 2 highlights both strengths and areas for improvement. A significant portion of the food handlers demonstrated strong knowledge in critical aspects of food safety. For instance, 100% of participants were aware that food handlers suffering from illnesses like diarrhoea, sore throat, and flu pose a contamination risk, indicating a clear understanding of the importance of maintaining good health to prevent foodborne diseases. Similarly, a large majority of participants, 86% to 95%, correctly identified key practices that minimize contamination, such as avoiding cross-contact between raw and cooked foods, maintaining personal hygiene by not wearing jewelry, and ensuring proper nail care.

However, despite these positive aspects, several gaps in knowledge were observed that require further attention. For example, 20% of food handlers did not recognize the risks associated with refreezing defrosted food, a critical issue in food safety. Additionally, although 85% of respondents correctly identified the safe operating temperature for refrigerators (1–5°C), this still leaves room for improvement, as previous studies have similarly highlighted deficiencies in this area (Martins et al., 2012; McIntyre et al., 2013). The results suggest that food handlers may not fully grasp the importance of correct refrigeration practices in preventing bacterial growth and foodborne illness.

These findings underscore the need for ongoing education and more targeted training. As demonstrated by previous studies, regular and hands-on food safety training can significantly enhance food handlers' knowledge, particularly in areas like proper food storage and handling practices (da Cunha et al., 2014; McIntyre et al., 2013). The study also points to the potential benefits of advanced training, such as HACCP and ISO 22000:2018, for food handlers working in high-risk environments like food courts and restaurants, where the risk of contamination is elevated due to the volume of food prepared and served. While the overall average knowledge score of 77% reflects a good foundational understanding of food safety, it also highlights the need for continuous learning to ensure that food handlers are equipped with the necessary skills and knowledge to minimize foodborne risks effectively. Moving forward, training programs should address specific gaps identified in this study, particularly concerning refrigeration practices, defrosting, and the use of proper equipment, to further strengthen food safety practices.

Table 2 Food handlers Knowledge on food safety

Statement	Agree n (%)
Reheating rice contributes to bacterial food poisoning (BFP)	20
Refrigeration and freezing do not destroy most bacteria	75
Refreezing defrosted food contributes to BFP	88
The safe operating temperature for a refrigerator is 1–5°C	85
Use of separate cutlery to prepare or handle raw and cooked foods minimizes food contamination	76
Not wearing rings, watches, necklaces minimizes food contamination	87
Contact between raw and cooked foods contributes to food contamination	86
The temperature range 5–47°C is suitable for the growth of most bacteria that spoil food	65
Pets in food premises can contaminate food	86
Cleaning and sanitizing utensils reduces the risk of food contamination	75
Wooden chopping boards are a high risk for food contamination	60
Using gloves to handle raw foods reduces the risk of food contamination	77
Eating, drinking, talking, and smoking when preparing or serving food increase the risk of food contamination.	65
Use of dish towels to wipe hands can contaminate food	82
Handwashing in sinks for washing cutlery increases the risk of food contamination	80
Keeping nails short and unpainted reduces the risk of food contamination	95
A healthy food handler can be a carrier of infectious food-borne diseases	82
A food handler suffering from diseases such as diarrhea, sore throat, syphilis and flu poses a risk of food contamination	100
Average	77

Food Safety Attitudes of Food Handlers

The attitudes of food handlers toward food safety, as presented in Table 3, reveal several important insights into their approach to food safety practices. The majority of participants (over 80%) exhibited positive attitudes towards key food safety measures, such as food safety training, proper cleaning procedures, adhering to cutlery color codes, and preventing food contamination. These findings are encouraging, as they suggest that a strong base of food handlers recognizes the importance of these critical practices.

However, the study also identified areas of concern. About 25% of participants reported that they would not inform their supervisors if they were suffering from diarrhoea, wounds, or cuts, and an equal proportion indicated they would not take sick leave in such circumstances. These attitudes pose a significant risk for the spread of foodborne illnesses during food preparation, handling, and serving. It is essential that these issues are addressed promptly to ensure that food handlers adhere to health and safety standards. Encouragingly, it is recommended that restaurant managers foster a Positive Food Safety Culture (PFSC) within their teams. PFSC refers to an environment where food safety is prioritized and embraced as a shared value by all members of the team, promoting proactive behaviors such as reporting illness and adhering to health protocols. This culture emphasizes open communication, mutual respect, and accountability, which can significantly enhance adherence to safety standards and reduce the risk of contamination. Building a Positive Food Safety Culture (PFSC) involves managers actively influencing attitudes and behaviors through leadership and creating a supportive atmosphere where food handlers are encouraged to follow food safety practices, including taking sick leave when necessary (Lück & Barros, 2019). Promoting positive attitudes toward health and safety can contribute significantly to minimizing contamination risks.

Another noteworthy finding was that approximately 20% of participants did not see the value in microbiological swabbing of palms and nails to assess the effectiveness of handwashing. Previous research underscores the importance of this practice, as hand contamination, particularly with bacteria like *Staphylococcus aureus* and *Salmonella,* remains a significant risk factor for foodborne illness. Studies have reported contamination in food handlers' hands with coagulase-positive staphylococci and found that a substantial proportion of food handlers tested positive for *Salmonella* or had high levels of total aerobic bacteria (Lee et al., 2017; Soares et al., 2012). These findings suggest that further education on the importance of hand hygiene and its microbiological implications is necessary.

To address these gaps, restaurant managers must focus on motivating food handlers to adopt positive food safety attitudes, which has been shown to be linked to better adherence to safe food handling practices (Seaman, 2010). Additionally, from a public health perspective, regular health inspections are critical in identifying and correcting any lapses in food safety practices. In cases of non-compliance with health and safety standards, authorities may need to consider the closure of non-compliant food premises to prevent the spread of foodborne diseases (Woh et al., 2016).

Statement	Agree n (%)
I am willing to learn about the basics of food hygiene and safety	95
I think restaurant managers should organize advanced training such as hazard analysis critical control point for food handlers	85
I will inform my supervisor if l have diarrhea, wounds or cuts	75
I will take sick leave if l have diarrhea, wounds or cuts	80
I try do my level best to always observe proper cleaning procedures	75
I am willing to observe cutlery color codes for different uses e.g. red for red meat, green for vegetables.	90
Preventing food contamination and spoilage is my key responsibility	75
Expired food should never be consumed	90
I consistently use gloves to handle no packed food even if my supervisor is absent	75
I do not need incentives to do my best to prevent food contamination	90
My number one reason for observing set food hygiene standards is not the fear of management's disciplinary measures	95
Swabbing of food handlers' palms and nails is useful for assessing the effectiveness of handwashing	80
Physical assessment of food handlers' personal hygiene is important for minimizing food contamination	89
Task performance supervision motivates me	67
Average	82.8

Table 3 Food Handlers Food Safety Attitude

Self- Reported Food Hygiene Practices of Food Handlers

The self-reported food safety practices of food handlers, as shown in Table 8, reveal both positive and concerning trends regarding hygiene practices in food preparation. While many food handlers reported adhering to proper hygiene protocols, there were notable discrepancies between self-reported practices and actual field observations. The majority of food handlers (98%) indicated that they wash their hands using detergent or disinfectant before handling food, which reflects good hand hygiene practice. However, field observations revealed a significant gap between self-reports and actual practices. A large proportion of food handlers were found not to use detergent or disinfectant when washing their hands before handling food or after contact with potentially contaminated materials. Non-sanitation of hands can lead to the transfer of pathogenic bacteria to food, posing a risk for foodborne illness (Abdul-Mutalib et al., 2012). Handwashing with antibacterial soap can effectively remove over 95% of coliform bacteria (Toshima et al., 2001), underscoring the importance of improved hand hygiene practices to reduce bacterial contamination risks.

Another concerning issue is the method of hand drying. While 89% of food handlers reported drying their hands using approved methods (such as disposable towels, air driers, or frisk drying), some were found to be using dish towels, which are not suitable for hand drying. Dish towels can harbor harmful bacteria, including *Staphylococcus aureus* and *Salmonella* (Lee et al., 2017; Stepanović et al., 2005), which can be transferred to food during preparation. In some cases, food handlers did not dry their hands at all. These practices highlight the need for training food handlers on proper hand-drying techniques to prevent contamination.

Additionally, approximately 50% of food handlers were observed washing their hands in sinks intended for washing cutlery, which is an unhygienic practice that can lead to cross-contamination. Previous studies have highlighted the risks associated with using the same utensils for both raw and cooked foods, as this can contribute to contamination (Abdul-Mutalib et al., 2012). The current study found that 94% of food handlers self-reported using separate cutlery for raw and cooked foods, but field observations showed that this practice was not always followed.

Despite these concerns, the self-reported data also indicated several positive hygiene practices. For instance, 96% of food handlers reported using detergent to clean food preparation areas, and 95% indicated that they rinse food preparation areas with clean water to remove detergent residues. Furthermore, a substantial percentage of handlers (92%) claimed to store raw and cooked foods separately, and 95% reported that raw vegetables and meat were stored separately in cold storage, which are essential practices for preventing cross-contamination.

Interestingly, the study found that 100% of food handlers reported having valid medical certificates, keeping their nails short and clean, and wearing clean aprons. These practices suggest a high level of awareness regarding personal hygiene and food safety standards.
In conclusion, while food handlers in this study demonstrated positive attitudes toward food safety and reported engaging in some good practices, there remain several critical areas that require attention. Specifically, discrepancies between self-reported practices and actual behaviors highlight the need for more robust training programs focused on improving hand hygiene, proper hand-drying methods, and the appropriate handling of utensils and food. By addressing these gaps, food establishments can better mitigate the risks of foodborne illness and promote a safer food environment.

Table 4 Food Handlers Food Safety Practices

Statement	Agree n (%)
Food preparation areas (FPAs) cleaned with at least a detergent prior to food preparation	96
FPAs rinsed with clean water to remove residues of detergents and disinfectants	95
Handwashing done using a detergent or disinfectant before handling food	98
Hands dried using approved method (e.g., disposable towels, air drier, frisk drying)	89
Smoking, sneezing and nose-poking not done when preparing food	70
Eating not done when preparing food	81
Separate storage of raw and cooked foods	92
Separate cold storage of raw vegetables and meat	95
Separate cutlery used for raw and cooked foods	94
Expired food should not be consumed	100
Handwashing not done in sinks for washing cutlery	72
Cutlery (e.g., knifes, spoons, cups) not handled by surfaces that come into contact with food	96
Non refreezing of defrosted foods	83
adequate thawing of food	89
No hand jewelry (e.g., necklaces, rings and watch)	100
Valid food handlers medical exam certificates	100
Hand nails kept clean and short	96
Hair covered with a cap or hairnet	100
Apron washed and clean	100
Protective gear not taken to potentially contaminated areas (e.g., toilet and home)	98
To be certain that food is safe to eat, one should cook it for the duration of the recommended time than smell or taste it	86
Average	87

Percentage distribution of respondents ' Knowledge, Attitudes, and Practices on Food Safety

The majority of food handlers were under 25 years of age (61.5%), with 75% of respondents being male. Food handlers demonstrated high awareness of sanitary practices in the workplace, including personal hygiene (100%) and handwashing (98%). The study revealed that food handlers had a strong understanding of basic food hygiene, as the majority of participants had received basic food safety training (90.4%) and HACCP training (84.6%). On average, the food safety knowledge, attitudes, and practices of food handlers were 77%, 82.2%, and 87%, respectively.

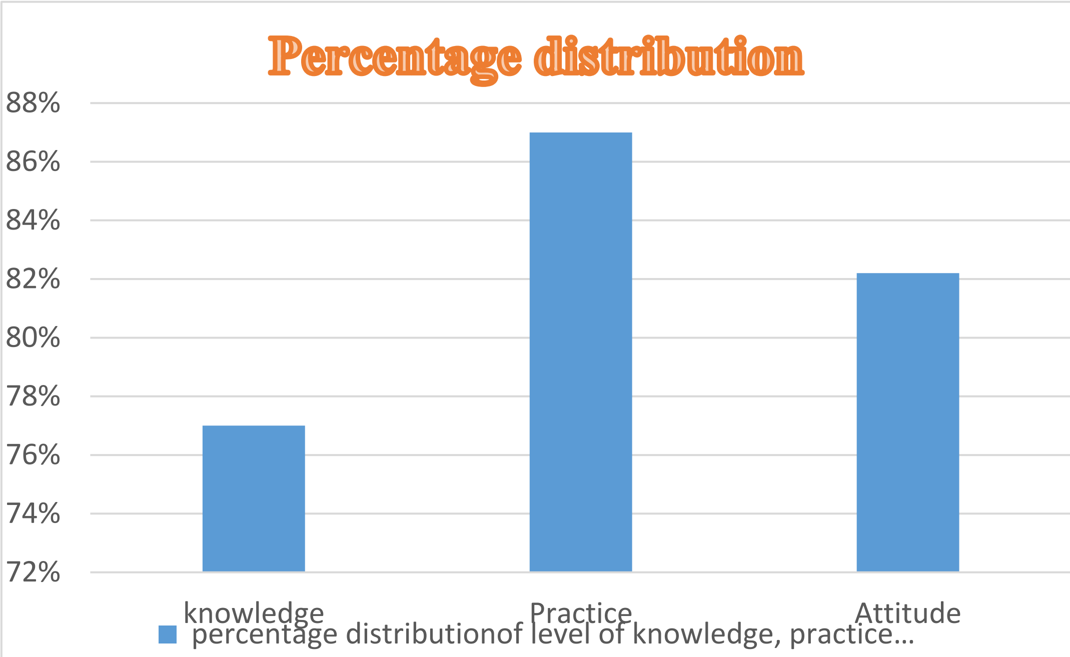


Figure 5 percentage Distribution of Level of Knowledge, Practices and Attitudes

Conclusion and Recommendations

The present study indicates that food handlers at Kandy City Centre generally exhibited satisfactory levels of food safety knowledge, attitudes, and practices. However, certain critical areas, particularly those related to cross-contamination control and time-temperature management, require further attention. While the handlers displayed good awareness of basic food hygiene practices, there is a need to strengthen the application of these practices, especially in areas where gaps were identified. These findings suggest that ongoing efforts are necessary to maintain and improve food safety standards in the workplace.

To address the identified gaps, it is recommended that food safety training programs be enhanced with a stronger focus on cross-contamination control and proper time-temperature management, which are essential for preventing foodborne illnesses. Additionally, training should move beyond theoretical knowledge and incorporate practical, hands-on learning experiences to better instill correct food safety practices. Building a positive food safety culture is crucial, where food handlers are encouraged to adopt proactive attitudes toward hygiene, report illnesses, and maintain a clean and safe working environment. Regular evaluations, updates on food safety regulations, and continuous monitoring and supervision by management are necessary to ensure that food safety standards are consistently met and followed.

References

Abdul-Mutalib, N. A., Syafinaz, A. N., Sakai, K., & Shirai, Y. (2012). An overview of foodborne illness and food safety in Malaysia. *International Food Research Journal, 19*(2), 465–473.

Azanaw, J., Gebrehiwot, M., & Dagne, H. (2021). Food safety knowledge, attitude, and practice of college students, Ethiopia, 2019: A cross-sectional study. *BioMed Research International, 2021*, 1–8. https://doi.org/10.1155/2021/5578294

da Cunha, D. T., de Rosso, V. V., & Stedefeldt, E. (2014). The role of theoretical food safety training on Brazilian food handlers' knowledge, attitude, and practice. *Food Control, 43,* 167–174. https://doi.org/10.1016/j.foodcont.2014.02.046

Gaur, S., & Singhal, R. (2015). Hazard analysis and critical control points (HACCP) implementation in the food industry: A review. *Food Control, 55*, 138–145. https://doi.org/10.1016/j.foodcont.2015.03.017

International Organization for Standardization. (2018). *ISO 22000:2018 – Food safety management systems – Requirements for any organization in the food chain.* Author. https://www.iso.org/standard/65464.html

Kendall, P., Medeiros, L. C., Hillers, V., Chen, G., & DiMascola, S. (2003). Food safety guidance for consumers: An evaluation of three consumer messages. *Food Protection Trends, 23*(9), 444–451.

Khan, U. A., Rahman, H., Younas, M., Jan, I. U., & Anjum, S. I. (2016). Food safety challenges towards safe, healthy, and nutritious street foods in Pakistan. *Journal of Food Science and Technology, 53*(6), 2565–2575. https://doi.org/10.1007/s13197-016-2215-9

King, T., Cole, M., Farber, J. M., Eisenbrand, G., Zabaras, D., Fox, E. M., & Hill, J. P. (2017). Food safety for food security: Relationship between global megatrends and developments in food safety. *Trends in Food Science & Technology, 68,* 160–175. https://doi.org/10.1016/j.tifs.2017.08.014

Lee, H., Abdul Halim, H., Thong, K. L., & Chai, L. C. (2017). Assessment of food safety knowledge, attitude, self-reported practices, and microbiological hand hygiene of food handlers. *International Journal of Environmental Research and Public Health, 14*(1), 55. https://doi.org/10.3390/ijerph14010055

López-Gálvez, F., Allende, A., Selma, M. V., & Gil, M. I. (2018). Prevention of Escherichia coli cross-contamination by different commercial sanitizers during washing of fresh-cut lettuce. *International Journal of Food Microbiology, 223,* 16–22. https://doi.org/10.1016/j.ijfoodmicro.2016.12.002

Lück, C., & Barros, C. (2019). Developing and assessing a positive food safety culture: A case study approach. *Journal of Food Safety, 39*(5), e12664. https://doi.org/10.1111/jfs.12664

Martins, R. B., Hogg, T., & Otero, J. G. (2012). Food handlers' knowledge on food hygiene: The case of a catering company in Portugal. *Food Control, 23*(1), 184–190. https://doi.org/10.1016/j.foodcont.2011.07.008

McIntyre, L., Vallaster, L., Wilcott, L., Henderson, S. B., & Kosatsky, T. (2013). Evaluation of food safety knowledge, attitudes, and self-reported hand washing practices in foodsafe trained and untrained food handlers in British Columbia, Canada. *Food Control, 30*(1), 150–156. https://doi.org/10.1016/j.foodcont.2012.06.034

Ministry of Health and Child Care. (1996a). *Public Health Act, Chapter 15:09*. Government of Zimbabwe.

Ministry of Health and Child Care. (1996b). *Food and Food Standards Act, Chapter 15:04*. Government of Zimbabwe.

Nyachuba, D. G. (2010). Foodborne illness: Is it on the rise? *Nutrition Reviews, 68(5)*, 257–269. https://doi.org/10.1111/j.1753-4887.2010.00286.x

Quested, T. E., Cook, P. E., Gorris, L. G. M., & Cole, M. B. (2010). Trends in technology, trade, and consumption likely to impact on microbial food safety. *International Journal of Food Microbiology, 139*(S1), S29–S42. https://doi.org/10.1016/j.ijfoodmicro.2009.12.015

Rebouças, L. T., Santiago, L. B., Martins, L. S., Menezes, A. C. R., Araújo, M. D. S., & Almeida, R. C. C. (2016). Food safety knowledge and practices of food handlers, head chefs, and managers in hotels' restaurants in Brazil. *Food Control, 73,* 372–381. https://doi.org/10.1016/j.foodcont.2016.08.036

Seaman, P. (2010). Food hygiene training: Introducing the food hygiene training model. *Food Control, 21*(4), 381–387. https://doi.org/10.1016/j.foodcont.2009.08.001

Sharif, L., & Al-Malki, T. (2010). Knowledge, attitude, and practice of Taif University students on food poisoning. *Food Control, 21*(1), 55–60. https://doi.org/10.1016/j.foodcont.2009.03.015

Soares, L. S., Almeida, R. C. C., Cerqueira, E. S., Carvalho, J. S., & Nunes, I. L. (2012). Knowledge, attitudes, and practices in food safety and the presence of coagulase-positive staphylococci on hands of food handlers in the schools of Camacari, Brazil. *Food Control, 27(1),* 206–213. https://doi.org/10.1016/j.foodcont.2012.03.016

Stepanović, S., Ćirković, I., Ranin, L., & Svabić-Vlahović, M. (2005). Biofilm formation by Salmonella spp. and *Listeria monocytogenes* on plastic surface. *Letters in Applied Microbiology*, 38(5), 428–432. https://doi.org/10.1111/j.1472-765X.2004.01606.x

Tewari, A., & Abdullah, S. (2015). *Bacillus cereus* food poisoning: International and Indian perspective. *Journal of Food Science and Technology,* 52(5), 2506–2516. https://doi.org/10.1007/s13197-014-1344-4

Toshima, Y., Ojima, M., Yamada, H., Mori, H., Tonomura, M., Hioki, Y., & Koya, E. (2001). Observation of everyday hand-washing behavior of Japanese, and effects of antibacterial soap. *International Journal of Food Microbiology, 68*(1–2), 83–91. https://doi.org/10.1016/S0168-1605(01)00443-4

Van der Meer, R. (2015). The role of food quality and safety in food chains. *International Journal of Dairy Technology, 68*(3), 314–319. https://doi.org/10.1111/1471-0307.12204

Woh, P. Y., Thong, K. L., Behnke, J. M., & Lewis, J. W. (2016). Evaluation of food safety knowledge, attitudes, and practices among migrant food handlers in Peninsular Malaysia. *Food Control, 64,* 160–167. https://doi.org/10.1016/j.foodcont.2015.12.038

World Health Organization. (2020). *Food safety: Key facts.* Author. https://www.who.int/news-room/fact-sheets/detail/food-safety

Field Screening of Rice Genotypes in Drought-Prone Rainfed Environment

B Karmakar[1]*, A Henry[2], SM Haefele[4], MHR Mukul[3], MM Hasan[3], A. Kumar[4]

1 Principal Scientific Officer, Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh.
3 Senior Scientific Officer, BRRI, Gazipur, Bangladesh.
2 Senior Scientist, International Rice Research Institute (IRRI), Los Banos, Philippines.
4 Former Senior Scientist, IRRI Los Banos, Philippines
* Corresponding author's email: biswajitbrri@gmail.com

Abstract

Rice yield significantly reduced due to drought stress in northwest Bangladesh. Drought tolerant rice genotypes could play a vital role to increase rice productivity and sustainability, and improve livelihood of farmers in drought prone rainfed ecosystem. Therefore, the study was undertaken to investigate the responses of rice genotypes under drought prone rainfed environment and to select rice genotypes tolerant for drought stress. A total of 30 rice genotypes were evaluated in drought prone rainfed high Barind tract at Godagari, Rajshahi, Bangladesh (24.27 N latitude, 88.21 E longitude, 40 masl) over two wet seasons (WS) July to December. Twenty five-d-old seedlings were transplanted in 25 x 15 cm spacing @ 3 seedlings hill^{-1} following randomized complete block design with 3 replications on 16 August of both the WS. Rainfall, temperature, drought severity, ground water depth, soil moisture content, soil water potential, phenology, leaf rolling and drying, spikelet sterility, dendogram clustering, rooting behaviors, yield and yield component data were measured to understand drought stress and to evaluate the performance of the genotype. Yield, yield components, leaf rolling, spikelet sterility and root characteristics varied significantly (p=0.001) among rice cultivars. Grain yield and harvest index of the tested rice genotypes ranged from 1.28 to 4.51 t ha^{-1} and 0.25 to 0.47, respectively based on drought severity. Across genotypes, 61% root biomass were located in the upper 0-10 cm soil layer, and decreased sharply in the layers below (27, 9 and 3% in the 10-20, 20-30 and 30-40 cm layer, respectively). Based on overall performance under drought stress, four rice genotypes (IR74371-70-1-1, IR83377-B-B-93-3, IRRI123 and IR83381-B-B-6-1) were selected as drought tolerant and BR7873-5*(NIL)-51-HR6 selected as drought escaping. The genotypes IR74371-70-1-1 and BR7873-5*(NIL)-51-HR6 were released as drought tolerant variety BRRI dhan56 and drought escaping BRRI dhan57, respectively. Consequently, the genotypic variation in our germplasm selection indicated considerable scope to develop drought tolerant variety through breeding for improvement of rainfed lowland rice.

Keywords: *Drought tolerance, leaf rolling, spikelet sterility, dendrogram clustering, harvest index.*

Introduction

Drought stress is a serious threat to sustainable rice production worldwide since water resources are limited and good quality irrigation water resources are scarce. However, drought occurrence and its effects on rice productivity often depend more on the rainfall distribution rather than total seasonal rainfall (Hijmans and Serraj, 2008). Intense drought can cause significant damage to the rice crop, often resulting in profound losses impacting farmers' families and the economy (Pandey et al., 2007). In many regions, drought induced losses in crop yields exceed losses from all other stresses, since both its severity and duration are critical (Farooq et al., 2009). The northwest part (Rajshahi region) of Bangladesh is such a drought prone area with low and erratic rainfalls, and limited irrigation potential (Saleh et al., 2000; Saleh and Bhuiyan, 1995). Erratic rainfall distribution causes drought frequently in this region, and results in yield losses that are generally higher than the damage due to flooding and submergence. The recurrent interval of drought is about 2−3 years, and drought occurs especially during the reproductive phase of wet season rice, which is generally classified as terminal drought (Islam, 2007). Often drought is also occurring at the beginning of the wet season, just prior to transplanting of rice seedlings. But apart from these regular events, any growth stage of rice crop can experience intermittent drought during the season due to uneven rainfall patterns (Kamoshita et al., 2008). These conditions are typical for about 0.16 M ha land of northwest Bangladesh which are rainfed and mainly drought prone (Saleh et al., 2000). The major portion of this region is part of the Barind tract which is a distinctive physiographic unit comprising a series of uplifted blocks of undulating terraces. The Barind has a higher elevation than the adjoining floodplain, with two terrace levels, one at 40 masl and another at 20−23 masl (Riches, 2008). Bangladesh as a whole has an average rainfall of about 2300 mm, ranging from 1000 to 5000 mm, but mean annual rainfall is lowest (1000-1200 mm) in the northwestern region (Karmakar et al., 2012; Saleh et al., 2000). Due to the effect of climate change, the weather of this region is getting extremer over the years. Karmakar et al. (2010) reported that only 800 mm rain occurred in Rajshahi during 2009. Annual average rainfall of the Rajshahi region showed a decreasing trend, declining by 3.1 mm per year since the last 50 years (Ferdous and Baten, 2011). Considering these changes occurring, comprehensive research on field screening of rice genotypes were undertaken in the drought prone rainfed environment of northwest Bangladesh.

The wet season (Aman) rice production in Bangladesh is dependent on monsoon rainfall. Farmers largely rely on rainfall and experience late transplanting of Aman rice when the monsoon is delayed, or yield reduction when drought occurs during the booting stage of rice in October. Delayed onset of the monsoon can create water stress for transplanted rice seedlings resulting to lower yields. Water stress due to extended delay of rainfall may even destroy rice seedlings (Mahmood et al., 2003) which is a recurrent phenomenon and an important constraint to rainfed rice production in Asia. However, rice yield is more affected by drought from panicle initiation to the grain filling stage. These stages occur late in the season when the probability of drought is higher than early in the season. Thus, late-season drought has a larger aggregated production impact than early-season drought (Pandey and Bhandari, 2008). Genotypes with increased drought tolerance are considered to be the first necessary step to improve the productivity of drought-prone rice-based systems. Consequently, research efforts were directed for many years towards the development of early-maturing and drought-tolerant rice varieties.

Another important element in drought tolerance are root systems. Rice root systems vary significantly among genotypes and soil conditions in drought prone rainfed environments (ref???). Root characteristics are strongly associated with drought resistance under rainfed conditions (Sharma et al., 1994). The root system of rice cultivars is strongly determined by genetics, however, it also affected by the soil moisture situation and crop management practices (Mambani et al., 1990; Sharma et al., 1987; Cruz et al., 1986). Reports showed that root length density (RLD) in lowland rice is affected by environmental conditions, genotype, management practices and soil depth (Tuong et al., 2002; Samson et al., 2002).

Recent research at the International Rice Research Institute (IRRI) has shown that direct selection for grain yield under drought stress is effective (Bernier et al., 2007; Venuprasad et al., 2007). IRRI and its National Agricultural Research and Extension System (NARES) partners identified several promising breeding lines that can produce 1.0−1.5 t ha^{-1} higher yield than current mega varieties in drought prone environments (Mackill et al., 1996). However, many of these promising genotypes have not yet been tested in drought prone rainfed environments of Bangladesh. But in order to identify the most promising and adaptable genotypes, screening and fine-tuning are required in the target environment. Therefore, a drought screening trial needed to be pursued in the drought-prone rainfed northwest Bangladesh. The main purposes of this study were to evaluate the performance of rice genotypes in drought-prone rainfed environment, and to select rice genotypes for drought tolerance based on root index and overall performance.

Materials and methods

Experimental site

The experiments were conducted in a farmer's field at Edulpur, Godagari, Rajshahi, Bangladesh (24°27′N latitude, 88°21′ E longitude, 43 masl) during the 2009 and 2010 wet season (WS). A drought prone rainfed topmost field in the *Barind tract* was selected for the experiment. The experimental site belongs to the Agro-ecological Zone (AEZ) 26, having silt loam to silty clay soils with a grey color (BARC, 2018). The topsoil at the experimental site had a soil pH of 5.8, a texture of 17% clay - 68% silt - 15% sand, soil organic carbon of 0.70%, total soil N of 0.078%, a C/N ratio of 9.0, available P_{Olsen} of 10.0 mg kg^{-1}, exchangeable $K_{exch.}$ of 0.21 me/100 g and a cation exchange capacity (CEC) of 6.8 cmol kg^{-1}.

Background of the tested rice genotypes

Thirty rice genotypes including 4 check varieties were tested for drought tolerance in the drought-prone rainfed conditions (Table 1). The rice genotypes were collected from the International Rice Research Institute (IRRI), the Bangladesh Rice Research Institute (BRRI), the Bangladesh Institute of Nuclear Agriculture (BINA) and farmers. IRRI and NARES partners identified several promising breeding lines that can produce 1.0–1.5 t ha^{-1} higher yield than current mega varieties under drought stress (Mackill et al., 1996). Some of the breeding lines were developed following crosses between two drought-tolerant breeding lines with the aim to accumulate positive alleles for drought tolerance from the two parents. Another set of breeding lines were developed by crossing drought-tolerant breeding lines with high-yielding popular drought-susceptible lines, with the aim to develop drought-tolerant breeding lines with high yield potential and good grain quality. All crosses were advanced through cyclic selection under reproductive stage drought stress from F_2 to F_6 generations based on drought tolerance, high yield, insect and disease tolerance, and good grain quality traits (amylose content, chalkiness etc.). The F_6 generation was transplanted under reproductive stage drought and selection was carried out in the nurseries. High-yielding lines under drought stress were bulked and forwarded to the observational yield trial (OYT). In the OYT, selection for high yield was repeated under reproductive stage drought stress and the best lines were forwarded to the advanced yield trials (AYT). In the AYT, selected lines were again tested with drought imposition at the reproductive stage. Selected drought tolerant genotypes from IRRI Philippines were then brought to Bangladesh for field screening in drought prone rainfed environments. Since there was no existing drought tolerant rice variety, 4 promising rice varieties were used as checks in the screening experiments.

Table 1: Rice genotypes tested in the experiments.

SN	Rice genotype	Parentage (Male parent/Female parent)

1	IR83376-B-B-71-1	IR71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
2	IR83381-B-B-137-1	IR72022-46-2-3-3-2 (DT)/IR77080-B-34-1-1 (DT)
3	IR83373-B-B-25-3	IR71700-247-1-1-2 (DT)/IR72875-94-3-3-2 (DT)
4	IR83376-B-B-130-2	IR71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
5	IR83381-B-B-6-1	IR 72022-46-2-3-3-2 (DT)/IR 77080-B-34-1-1 (DT)
6	IR83372-B-B-33-2	IR 71700-247-1-1-2 (DT)/IR 57514-PMI 5-B-1-2 (DT)
7	IR83381-B-B-55-4	IR72022-46-2-3-3-2 (DT)/IR77080-B-34-1-1 (DT)
8	IR83373-B-B-81-2	IR71700-247-1-1-2 (DT)/IR 72875-94-3-3-2 (DT)
9	IR83383-B-B-141-2	IR72022-46-2-3-3-2 (DT)/IR57514-PMI 5-B-1-2 (DT)
10	IR83376-B-B-150-1	IR 71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
11	IR83376-B-B-110-2	IR 71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
12	IR83376-B-B-24-2	IR 71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
13	IR83383-B-B-129-4	IR 72022-46-2-3-3-2 (DT)/IR 57514-PMI 5-B-1-2 (DT)
14	IR74371-70-1-1	IR 55419-4*2 (DT)/WAY RAREM (DS)
15	IR83387-B-B-27-4	IR 72022-46-2-3-3-2 (DT)/SAMBHA MAHSURI (DS)
16	IR83614-427-B	IR 78875-131-B-1-2 (DT)/IR 64 (DS)
17	IR83388-B-B-108-3	IR 72022-46-2-3-3-2 (DT)/SWARNA (DS)
18	IR83377-B-B-93-3	IR 71700-247-1-1-2 (DT)/SAMBHA MAHSURI (DS)
19	IR83388-B-B-8-3	IR 72022-46-2-3-3-2 (DT)/SWARNA (DS)
20	IR83387-B-B-134-2	IR 72022-46-2-3-3-2 (DT)/SAMBHA MAHSURI (DS)
21	IRRI123	IR 47761-27-1-3-6 (DT)/IRRI 108 (DS)
22	IR83377-B-B-48-3	IR 71700-247-1-1-2 (DT)/SAMBHA MAHSURI (DS)
23	IR78937-B-3-B-B-1	IR 47701-6-B-1 (DS)/IR 55435-05 (DT)
24	BR7870-5*(Nils)-8-HR4	BR10 (DS)/5*CR146-7027-224 (DT)
25	BR7873-5*(NIL)-51-HR6	BR11 (DS)/5*CR146-7027-224 (DT)
26	NERICA4	WAB 56-104 (DT)/CG 14 (DS)
27	IR64 (Check)	IR 5657-33-2-1 (DT)/IR 2061-465-1-5-5 (DS)
28	Binadhan-7 (Check)	TNDB100/ Kienguyen
29	BRRI dhan49 (Check)	BR4962-12-4-1/IR33380-7-2-1-3
30	Guti Swarna (Local check)	Popular variety of northwest Bangladesh

NB: SN-Serial number, DT-Drought tolerant and DS-Drought susceptible

Experimental protocol and management practices

Seedlings were raised in a seedbed according to the traditional farm practice. Seeds were soaked in water for 24 h and incubated until the radicle emerged. Sprouted seeds were broadcasted at 80 g m^{-2} on 22 July of the two successive wet seasons 2009 and 2010. Fertilizers containing N, P, K and S at 46, 20, 30 and 18 kg ha^{-1}, respectively, were applied in the seedbed during final land preparation (BRRI, 2019). Urea (N at 46 kg ha^{-1}) was top dressed at 10 days after seeding (DAS). Wet land soil preparation with puddling was done according to the common practice. Initially, the land was ploughed once with a country plow, followed by two power tiller passes and laddering. After 7 days, the land was finally prepared by one pass with a power tiller, followed by laddering to level the land. The levee around the plot was newly made. Fertilizers used were urea, TSP, MOP, gypsum and zinc sulfate, applied at a rate of N, P, K, S and Zn of 82, 15, 38, 10.6 and 2.7 kg ha^{-1}, respectively. The full amount of TSP, MOP, gypsum, zinc sulfate and one-third of the urea were applied basally during the final land preparation. The remaining urea was top-dressed in two equal splits at 20 days after transplanting (DAT) and 40 DAT synchronized with rainfall or wet soil conditions as the experiment was conducted under rainfed conditions. The experiment was laid out following a randomized complete block design with 3 replications. Twenty five-day-old seedlings were transplanted with a 25 x 15 cm spacing (BRRI, 2019) at 3 seedlings hill^{-1} on 16th August in both years. Transplanting of rice seedlings purposely delayed from optimum planting (July) to address terminal drought at reproductive stage. Unit plot size was 2.5 m x 4 m. Based on the drought characteristics of the experimental site, transplanting was purposively delayed compared with the normal transplanting time (July) of Aman rice (wet season) to increase the potential exposure to drought stress (Torres et al., 2012). The levee around the experimental plots was opened at 28 DAT to ensure severe drought stress at reproductive stage of the crop. Uniform and standard management practices were followed to control weed and pest in the plots.

Sampling and data collection

Recommended procedures were followed to collect data for yield and yield components, agronomic parameters, and drought stress measurements (Gomez, 1972; Gomez and Gomez, 1984; IRRI, 2002; IRRI, 1994). At maturity, tillers and panicles hill^{-1}, empty and full spikelets hill^{-1}, and 1000-grain weight were counted from 2 x 2 hill sampling units from three places (12 hills plot^{-1}) sampled on a diagonal in each plot (Gomez, 1972). From the center of each plot, 6-m^2 areas were harvested for determination of grain and straw yields at maturity. After harvest and threshing, grains were sun-dried, and weight and moisture content were measured. Grain yield was adjusted to 14% moisture content, and expressed in t ha^{-1}.

Climate monitoring and drought stress characterization
Meteorological data (daily rainfall, air temperature, evaporation and sun shine hour) were collected from the mini-weather station at Edulpur, Godagari, Rajshahi, Bangladesh set up by BRRI Rajshahi and very close (25 m) to the experimental plots.

Rainfall status
The experimental site at Edulpur, Godagari, Rajshahi received the lowest seasonal rainfall (744 mm) since a decade in the year 2009. Of the total, 210 mm occurred in August, which also had 17 rainless days (Fig.1). In September, rainfall was 181 mm but 80% of that occurred in the 1st half of the month and 21 days were rainless. There were 27 rainless days in October and only 15.8 mm rainfall was observed (Fig. 1). Consequently, the crop of 2009WS experienced severe drought stress during the reproductive phase. In contrast, 897 mm rain occurred at the experimental site in the WS 2010 of which 115, 160, 192, 133 and 2.4 mm rain occurred in July, August, September, October and November, respectively (Fig. 2). Rainfall from July to October 2010 was well distributed (Fig. 2). Therefore, especially the short and medium duration genotypes did not face drought stress in the 2010WS. However, the long duration genotypes flowering after the 3rd week of October experienced medium drought stress.

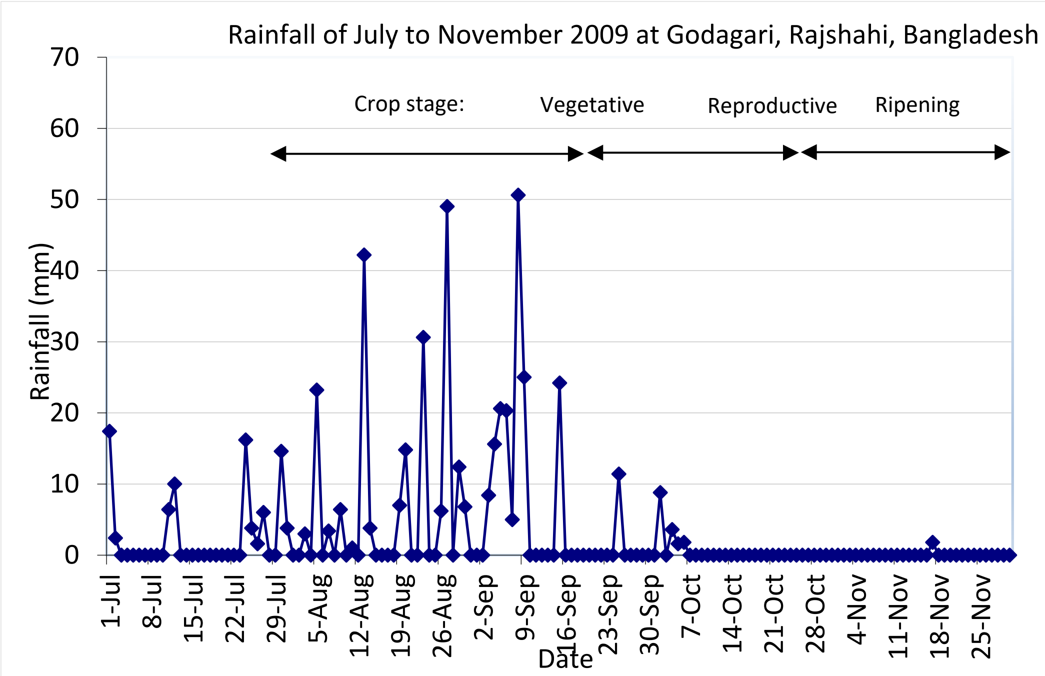


Fig. 1. Crop stage and rainfall distribution at the experimental site during July-November 2009 (Source: Mini weather station of BRRI Rajshahi at Godagari, Rajshahi, Bangladesh).

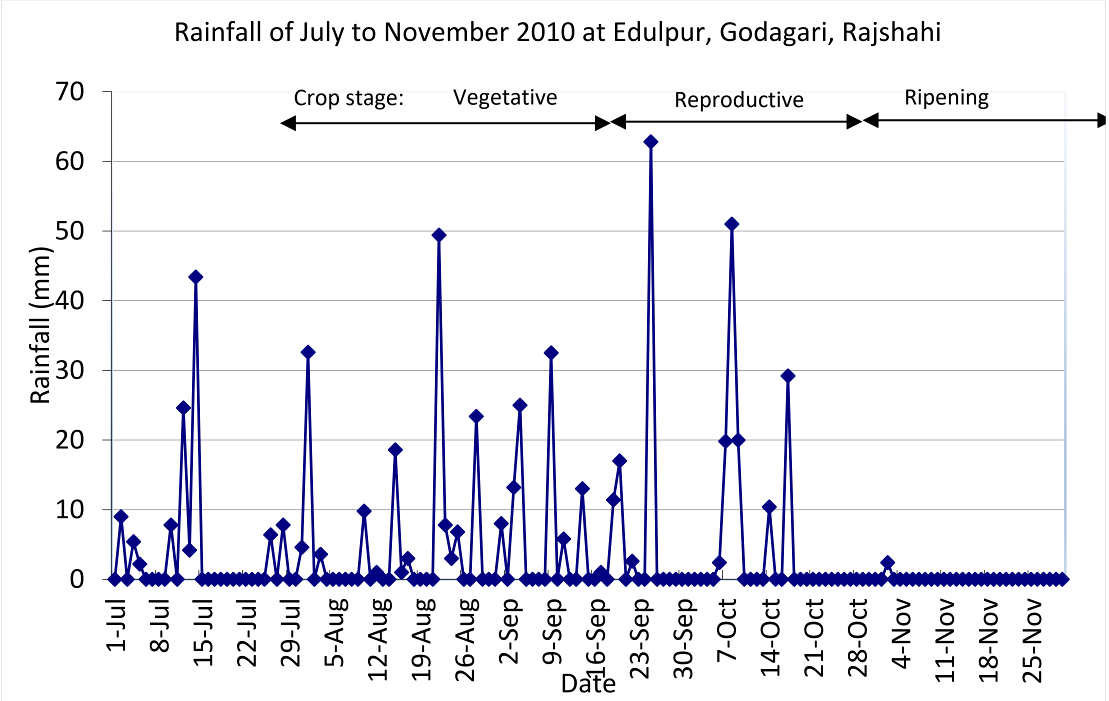


Fig. 2. Crop stage and rainfall distribution at the experimental site during July-November 2010 (Source: Mini weather station of BRRI Rajshahi at Godagari, Rajshahi, Bangladesh).

Temperature status

Monthly mean temperatures from July to November of 2009 were comparatively higher than in 2010. Temperature fluctuation of both years followed similar trends, but the day-night temperature difference in October to November 2009 was higher than in 2010. Monthly mean maximum and minimum temperatures at the site from July to November were 32.1 and 20.5 °C in 2009, and 29.4 and 25.2 °C in 2010. The mean daily sunshine duration was 6.14 h in the 2009WS and 5.65 h in the 2010WS.

Drought measuring protocol

Drought stress was assessed indirectly by measuring soil moisture content, soil water potential, drought amount quantification, leaf rolling and drying score, spikelet sterility percentage, phenotypic acceptability and root characteristics. The methods are outlined below.

Ground water depth measurement

Ground/perched water table was monitored daily with PVC-pipe piezometers of 1 m length and 0.05 m diameter. The lower 0.8 m end of the pipe, which was below ground, was perforated with 4 mm holes. Three PVC pipes were installed in the experimental plots and the water level was regularly monitored in relation to the upper end of the pipe. Water table depth in the experimental field fell sharply from 13th September onward in the 2009 WS (Fig. 3). It reached 0.8 m below ground on the 25th September and stayed there until the end of the 2009 season. In the 2010 WS, the perched water table started to fall from the 27th September but fell slowly. This confirmed that the 2009 WS experienced a severe drought while the 2010-WS was only a moderately drought for the crop.

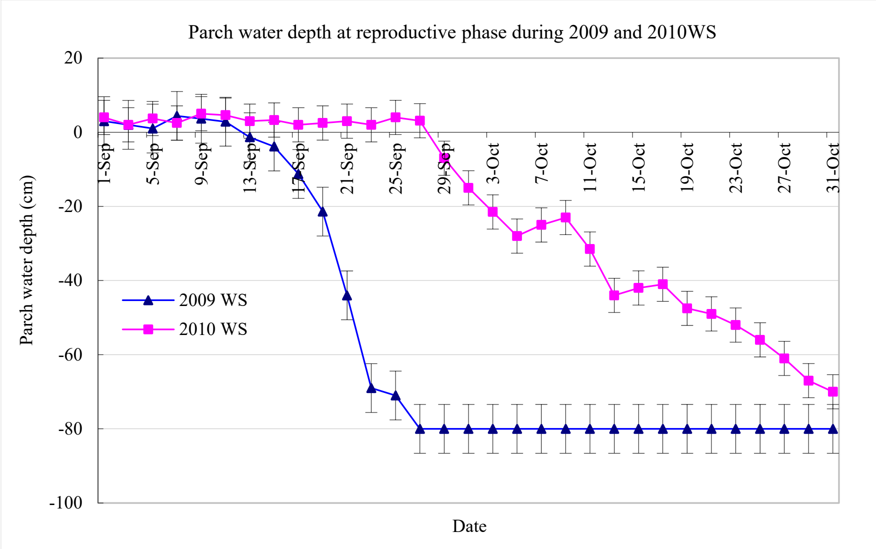


Fig. 3. Parch water depth at the experimental field during 2009WS and 2010WS at Godagari, Rajshahi, Bangladesh.

Soil moisture content measurement

The levee surrounding the plots was cut at 28 DAT, so that the soil dried faster during rainless days. Cracks developed in the soil of the plots quickly and became deeper during the season. Three soil samples from 0-0.2 m depth of each replication were taken by auger twice weekly from 30 DAT until the ripening stage. After recording the initial weight, the soil samples were wrapped in aluminum foil and oven dry weight was determined after drying at 70 ˚C temperature for 72 h. Initial and oven dry weight of the soil samples were used to calculate soil moisture content as a measure of soil water status in the field. Soil moisture content was calculated using the following formula:

$$\text{Soil moisture content (\%)} = \frac{\text{W1-W2}}{\text{W1}} \times 1 - W \quad (1)$$

where W1 is the initial weight of the sample and W2 is the oven dried weight of the sample.

Soil moisture status of the experimental plots during the seasons is shown in Fig.4. In general, soil moisture during the 2009 WS was much lower than in the 2010 WS. It decreased to 8% at the last week of October during 2009 WS while it was still 20% at the end of the 2010 WS.

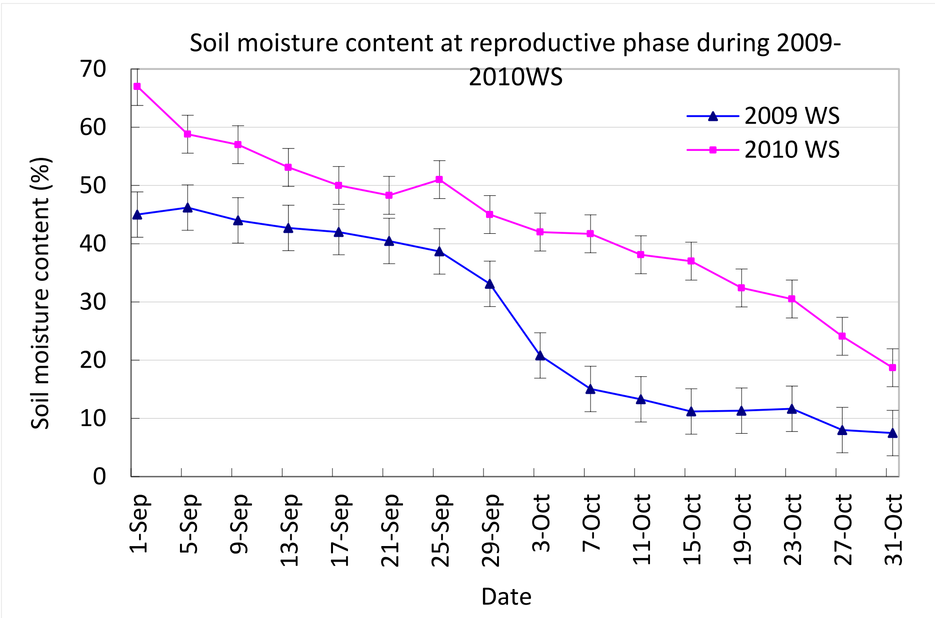


Fig. 4. Soil moisture content at the experimental fields during 2009WS and 2010WS at Godagari, Rajshahi.

Soil water potential measurement using Tensiometer

Soil water potential measured with tensiometers (give specs of the equipment used???) after draining the plots at 28 DAT in both seasons is shown in Fig. 5. The soil water potential declined generally but fluctuated up and down in both early seasons due to alternating periods of drought and rainfall (Fig. 5). Fluctuating soil water potentials continued longer in the 2010 WS. A steady decline started from 7th October 2009 but only the 17th October 2010.

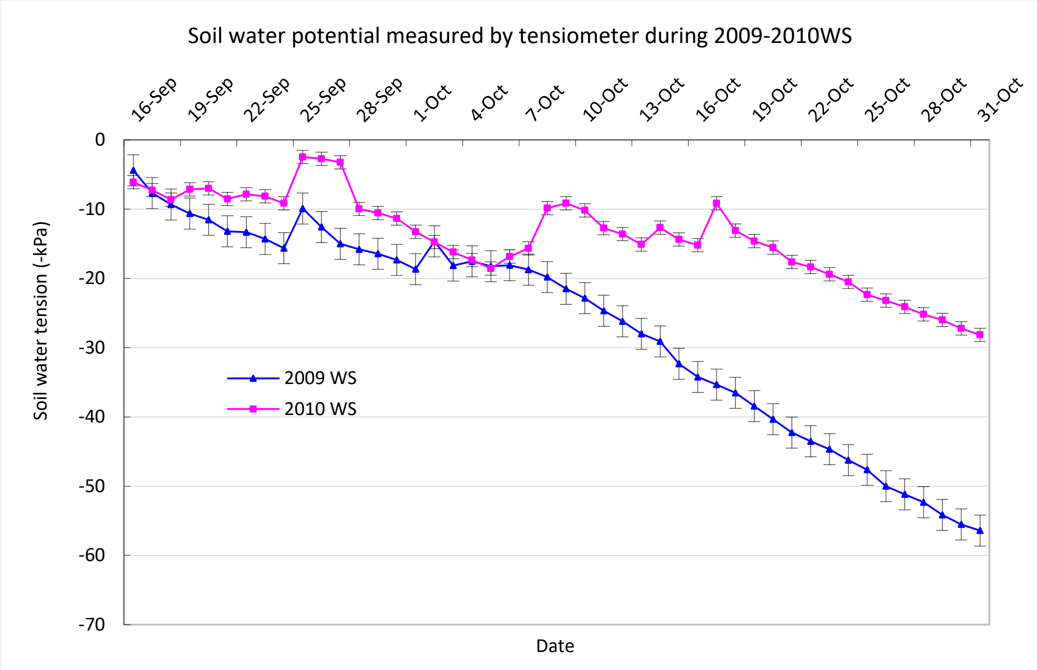


Fig. 5. Soil water potential at the experimental fields during 2009WS and 2010WS at Godagari, Rajshahi, Bangladesh.

Drought Severity quantification

Drought Severity was determined using Drought Simulation Model (Islam et al., 2007) and expressed in water deficit compared to a simulated normal watered crop. Drought severity was considered as the water deficit in the soil being equal to the unfulfilled demand of a simulated normal crop and drought duration was the period of time during which the crop suffered from drought. Drought severity was the cumulative amount of drought for that duration. Based on the seeding and transplanting date of the crop in 2009 and 2010WS, drought amount and duration were quantified in three crop stages like vegetative (08 August to 15 September), reproductive (16 September to 15 October) and ripening stage (16 October to 15 November). The model assumes two storages of water; the first one is called surface water storage (SWS) and the second one is soil moisture storage (SMS). SWS contain standing water in the field above the soil surface and SMS contains soil moisture in the root zone soil. The ET demand of crop is met from the first storage (SWS) if there is water in it on the dry days. When first storage is exhausted then ET demand is met from the second storage (SMS). If the SMS is unable to satisfy ET demand in the continued dry period, and the crop experiences drought stress. The amount of drought is considered to be equal to ET demand that remains unfulfilled due to inadequate moisture in the soil.

Leaf-rolling and Leaf-drying

Drought sensitivity of the germplasm tested was measured through scoring of leaf rolling and drying during the vegetative and reproductive stage of the crop following the protocol developed by IRRI, using a score between 0 (leaves healthy; no rolling) and 9 (leaves tightly rolled) (IRRI, 2002).

Spikelet fertility and sterility

Drought stress was also measured indirectly through the level of spikelet sterility, using a score between 1 (less than 20% sterility) and 9 (more than 90%) (IRRI, 2002).

Root Biomass

Roots from the depth of 0-10, 10-20, 20-30 and 30-40 cm were collected during harvest, by soil core sampler (10 cm diameter auger) from the center of a hill and 5 cm apart from the center of hills with average tiller number (Karmakar et al., 2004). The soil core sampler was placed on the soil surface and hammered in to 40 cm depth (Uddin et al., 2009). Five samples were taken from each plot. After sampling, soil cores were divided into 0-10, 10-20, 20-30 and 30-40 cm layers with a knife. Each layer was kept on an iron net (2 mm mesh) and the roots were separated from soil by applying water. After washing each sample was spread out and root length was measured with a Comair Root Length Scanner (Hawker De Havill and Victoria Ltd., Australia). After root length scanning, root samples were dried in an oven at 70 °C for 48 hours (Henry et al., 2012; Uddin et al., 2009; Karmakar et al., 2004). A high precision balance (milligram) was used to measure the dry weight of root biomass.

Statistical analysis

Data recorded in the experiments were statistically analyzed following procedures described by Gomez and Gomez (1984). Analysis of variance (ANOVA) was conducted using statistical software CropStat 7.2, cluster constructed by JMP 7.0.2 based on phenotypic characteristics and diversity analyses were done by GenStat 5.3. Means were compared with the least significant difference (LSD) test.

Results and Discussion

Drought severity and drought duration quantification

The genotype screening experiment was conducted under rainfed conditions and the bund was cut at 28 days after transplanting (DAT). Consequently, the crop was fully depended on rainfall. The crop of the wet season 2009 received rains up to the vegetative stage while the crop of 2010 received rainwater up to reproductive stage. Therefore, drought severity and drought duration were higher in 2009 WS than in the 2010 WS. Drought severity at vegetative, reproductive and ripening stage in 2009 was 2, 93 and 152 mm water deficit, respectively while it was 9, 22 and 76 mm water deficit in 2010 WS (Fig. 6). Accordingly, the total water deficit (247 mm) was remarkably higher during in 2009 WS than 2010 WS (107 mm). For drought duration, the data followed the trend of drought amount. Drought duration at vegetative, reproductive and ripening stage was 1, 22 and 20 days in 2009 but it was 3, 8 and 14 days in 2010 WS. Therefore, the crop of the 2009 WS faced 43 days drought stress whereas the stress duration was only 25 days in 2010 WS. Consequently, the crop of the 2009 WS experienced a severe drought stress while it faced moderate drought stress in the 2010 WS.

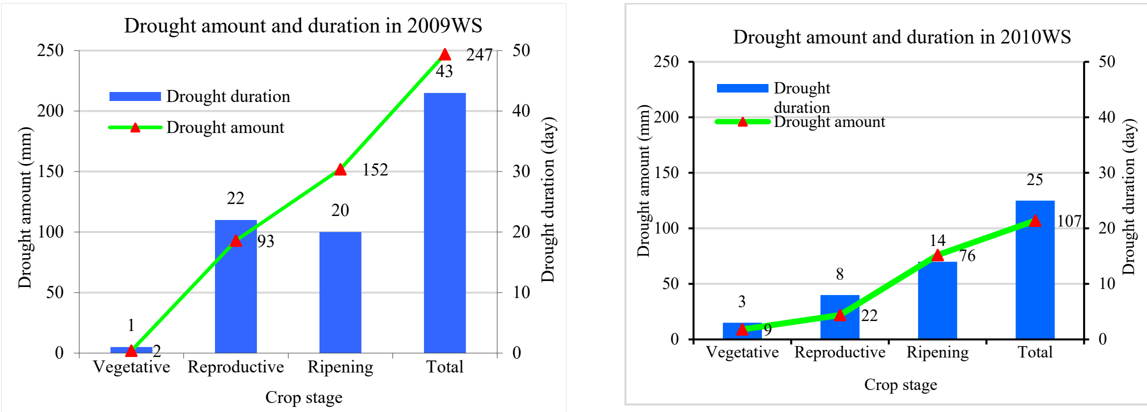


Fig 6. Drought amount and drought duration in the experimental field during 2009 and 2010WS at Godagari, Rajshahi, Bangladesh.

Genotype clustering through dendogram regarding leaf rolling and drying, spikelet sterility; and phenotypic acceptability

A dendogram was constructed using a distance matrix which was calculated from phenotypic acceptability, leaf-rolling, leaf-drying and spikelet fertility values. This dendogram determined the relationship among the tested 30 rice genotypes and grouped them into 3 clusters (Fig. 7). The distribution pattern indicated that cluster I comprised the highest number of tested entries (22), followed by cluster II (2), and cluster III (6) (Table 2). Among the clusters, genotypes in cluster III had the highest score having lowest values of phenotypic acceptability, leaf rolling, leaf drying and spikelet sterility scores, indicating that these genotypes possess more drought tolerance compared to other clusters. In contrast, the mega varieties BRRI dhan49 and Guti Swarna were placed in cluster II which showed more susceptibility to drought stress. Cluster I showed intermediate drought tolerance, having values of the parameters phenotypic acceptability, leaf-rolling, leaf-drying and spikelet fertility in between cluster II and III. Cluster mean of 30 rice genotypes was the highest (8.167) in phenotypic acceptability at the reproductive stage ranging from 1.267 to 8.167 (Table 3). Differences in cluster means existed for almost all the characters studied. Inter and intra cluster distance varied from cluster to cluster (Table 3). Inter cluster distance was the highest (10.936) in between cluster II and III that was followed by cluster I and III (7.245) and the lowest was in cluster I and II (5.952). Intra cluster distances were calculated from the value of distance matrix of tested 30 rice genotypes. Genotypes in cluster I showed the highest intra cluster distance (0.745), followed by cluster III (0.615) and cluster II (0.382). Relative contribution towards divergence is presented in Table 4. Among characteristics for drought tolerance, the value of phenotypic acceptability at vegetative, leaf-rolling and leaf-drying at vegetative and reproductive stage of the genotypes showed positive divergence in vector I (Table 4). It indicated that these characters contributed more towards divergence among the genotypes. In contrast, the values of phenotypic acceptability at vegetative stage and spikelet sterility were negative in vector I contributed less toward divergence. All the parameters scored at reproductive stage showed positive value in vector-II while it was negative in case of scored recorded at vegetative stage (Table 4). The double positive values generally contributed higher in divergence. In the present study, three characters such as phenotypic acceptability, leaf-rolling and leaf-drying at reproductive stage showed double positive value in both the vectors indicated that those characters contributed most towards divergence. In contrast, single character phenotypic acceptability at vegetative showed double negative value in both the vectors. Spikelet sterility showed positive value in vector-II and negative value in Vector-I indicated that it also contributed remarkably for divergence.

Table 2. Intra-cluster (Diagonal) and inter-cluster (D^2) divergence values of 30 rice genotypes.

Clusters	Cluster I	Cluster II	Cluster III
Cluster I	**0.745**		
Cluster II	5.952	**0.382**	
Cluster III	7.245	10.936	**0.615**

NB: Bold figures denote intra cluster distance

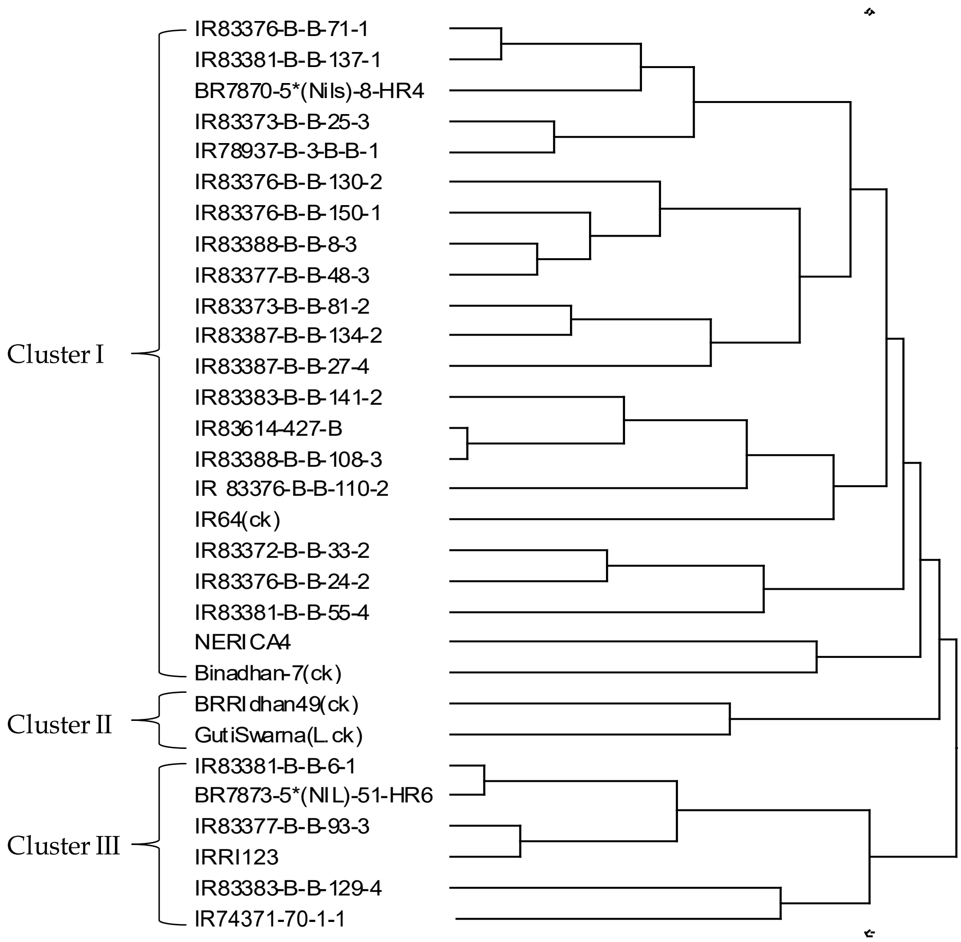


Fig.7. Dendogram of 30 rice genotypes based on phenotypic acceptability, leaf rolling, leaf drying and spikelet fertility under drought prone rainfed environment.

Table 3. Cluster means of the characteristics of 30 rice genotypes.

Characteristics	Cluster mean		
	I	II	III
Phenotypic acceptability at vegetative stage	3.887	6.189	2.333
Phenotypic acceptability at reproductive stage	6.133	8.167	2.550
Leaf rolling at vegetative stage	1.778	1.953	0.200
Leaf rolling at reproductive stage	3.900	4.044	1.267
Leaf drying at vegetative stage	1.533	1.589	0.267
Leaf drying at reproductive stage	3.444	3.993	1.433
Spikelet fertility	4.511	4.560	3.667

Table 4. Characters contribution towards divergence among the 30 rice genotypes.

Characteristics	Vector I	Vector II
Phenotypic acceptability at vegetative stage	-0.0511	-0.7070
Phenotypic acceptability at reproductive stage	0.2904	0.1821
Leaf rolling at vegetative stage	0.5026	-0.9340
Leaf rolling at reproductive stage	0.1956	0.2377
Leaf drying at vegetative stage	0.6383	-1.7975
Leaf drying at reproductive stage	1.2135	0.9422
Spikelet fertility	-0.2526	0.3186

Genotypic variation on yield, yield attributes and agronomic parameters under drought stress

Significant genotypic difference existed among the rice cultivars for grain yield, yield components and agronomic parameters in both the 2009 and 2010WS (Table 5). Across the genotypes, IR83377-B-B-93-3 attained the highest grain yield (3.65 t ha^{-1}) followed by IRRI 123 (3.53 t ha^{-1}) and IR74371-70-1-1 (3.52 t ha^{-1}) in 2009WS under severe drought stress. Quite the reverse, locally popular mega variety Guti Swarna produced the lowest grain yield (1.30 t ha^{-1}) followed by BRRI dhan49 (1.36 t ha^{-1}). The genotype NERICA4 gave 2.10 and 2.71 t ha^{-1} grain yield during 2009 and 2010WS, respectively. In general, yield of the tested genotypes was lower in 2009WS than 2010 WS as the crop of 2009 WS faced more drought stress at reproductive phase compared to 2010 WS (Fig. 6). Grain yield ranged from 1.28 to 3.65 t ha^{-1} in 2009WS while it was 2.44 to 4.51 t ha^{-1} in 2010WS. Similarly, percentage of grain yield reduction in 2009 over 2010 ranged from 14 to 57.0% (Table 5). Grain yield reduction was the highest (57.0%) in the Guti Swarna while the lowest (14%) was in IR74371-70-1-1 followed by IR83377-B-B-93-3 (19%) and IRRI 123 (20%) in 2009WS over 2010WS. In general, harvest index was lower than the optimum level of high yielding variety and it was also lower in 2009WS than 2010WS. Across the genotypes and years, most of the genotypes contained lower harvest index with an average of 0.37 ranging from 0.25 to 0.45 in 2009WS while it was 0.41 ranging from 0.33 to 0.47 during 2010WS. Harvest index was the highest (0.45) in IR83377-B-B-93-3 followed by IR74371-70-1-1 (0.44) and IRRI (0.44) in 2009WS. It was the lowest (0.25) in Guti Swarna in 2009WS while it was the lowest (0.27) in BRRI dhan49 in 2010WS. Days required to maturity and plant height remarkably affected by the genotypes (Table 5). Days to maturity ranged from 102 to 134 during 2009WS while it was 105 to 136 days in 2010WS. In general, soil water tension was higher in 2009WS compared to 2010WS (Fig. 5). Across the experimental years and genotypes, plant height varied from 87 to 111 cm due to water stress. Panicle production m^{-2} ranged from 167 to 252 in 2009 while it was 190 to 267 during 2010WS. Moreover, the mega variety BRRI dhan49 and Guti Swarna produced significantly lower panicles m^{-2} than the highest one. The tested genotypes expressed high significant variability regarding spikelet sterility (Table 5). Sterility percentage was the highest (62%) in Guti Swarna during 2009WS despite the fact that the highest percentage of sterility (42%) was found in BRRI dhan49 and IR83376-B-B-24-2 in 2010WS. In contrast, IR74371-70-1-1 and IR83377-B-B-93-3 performed better with the lowest sterility 26 and 22%, respectively. Strong significant differences in respect of 1000-grain weight of the genotypes found in both the experimental years. Among the cultivars, IR83387-B-B-27-4 produced grain with highest 1000-grain weight (23.8 and 24.3 g in 2009 and 2010, respectively) at the same time as the genotype BR7873-5*(NIL)-51-HR6 gave constantly the lowest 1000-grain weight of 20.7 and 21.0 g in 2009 and 2010, respectively.

Relationship of grain yield and yield attributes

Correlation between yield and yield parameters was highly significant in both the experimental years (Table 6). Moreover, Fig.8 and 9 showed the relationship among grain yield with panicles m^{-2}, spikelet sterility, 1000-grain weight, plant height, biomass and harvest index during 2009 and 2010WS. The highest R^2 values (0.927 and 0.853 in 2009 and 2010Ws, respectively) found in the relation of yield and biomass followed by harvest index (Fig 7 and 8). Compound interrelationship among various traits was found between yield and yield components determining one depended variable such as grain yield. Grain yield showed positive association with all the parameters except spikelet sterility. Panicles m^{-2}, biomass and harvest index were high positively related with grain yield while plant height and 1000-grain weight low positively related. In contrast, spikelet sterility was high negatively related with grain yield during both the experimental years.

Table 5. Phenology, yield and yield components of the rice genotypes under drought prone rainfed environment at Godagari, Rajshahi Bangladesh during 2009 and 2010WS.

Genotype	Grain yield (t ha^{-1})		Yield reduction (%) in 2009 over 2010	Harvest Index		Growth duration (day)		Plant height cm)		Panicles m^{-2} (no.)		Sterility (%)		1000-grain wt. (g)	
	2009	2010		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
IR 83376-B-B-71-1	1.68	2.92	43	0.34	0.40	110	112	102	104	190	206	46	38	22.6	23.5
IR 83381-B-B-137-1	1.87	3.02	38	0.36	0.41	111	113	103	105	192	212	45	39	23.1	23.8
IR 83373-B-B-25-3	1.50	2.57	42	0.31	0.38	109	111	108	109	187	203	47	40	22.8	23.3
IR 83376-B-B-130-2	2.20	3.12	29	0.37	0.39	109	110	106	107	201	226	38	35	22.7	23.2
IR 83381-B-B-6-1	3.11	4.07	22	0.41	0.43	108	110	104	109	212	235	29	24	23.3	23.7
IR 83372-B-B-33-2	1.46	2.58	44	0.33	0.36	107	109	95	97	188	210	51	41	22.7	23.4
IR 83381-B-B-55-4	1.35	2.38	43	0.31	0.37	110	113	104	106	174	190	52	43	22.3	23.2
IR 83373-B-B-81-2	1.89	3.01	37	0.36	0.41	105	108	95	96	196	220	45	40	22.6	22.9
IR 83383-B-B-141-2	2.55	3.78	33	0.41	0.45	108	111	102	104	213	233	35	30	22.9	23.3
IR 83376-B-B-150-1	2.35	3.25	26	0.39	0.41	109	110	108	111	206	222	37	32	23.2	23.5
IR 83376-B-B-110-2	2.76	3.87	29	0.43	0.46	111	113	103	105	220	242	34	29	22.7	23.5
IR 83376-B-B-24-2	1.41	2.44	42	0.30	0.35	109	111	92	93	167	199	52	42	22.4	22.7
IR 83383-B-B-129-4	2.91	3.92	26	0.42	0.46	113	115	103	108	220	233	31	27	23.0	23.3
IR74371-70-1-1	3.52	4.11	14	0.44	0.47	105	108	106	110	228	251	26	23	23.2	23.4

IR 83387-B-B-27-4	2.14	3.07	30	0.36	0.39	111	114	92	97	213	229	42	37	23.8	24.3
IR83614-427-B	2.28	3.17	27	0.37	0.40	103	105	87	90	219	235	41	35	22.5	23.2
IR 83388-B-B-108-3	2.37	3.41	31	0.39	0.42	109	112	100	104	217	235	37	31	22.7	23.2
IR 83377-B-B-93-3	3.65	4.51	19	0.45	0.47	112	115	103	110	245	261	26	22	23.3	23.6
IR 83388-B-B-8-3	2.36	3.26	28	0.37	0.40	112	115	103	106	213	231	43	34	22.6	23.4
IR 83387-B-B-134-2	2.17	3.08	29	0.35	0.38	113	116	102	107	197	217	44	35	22.9	23.4
IRRI 123	3.53	4.40	20	0.44	0.47	116	120	103	109	245	267	28	24	23.2	23.7
IR 83377-B-B-48-3	2.21	3.10	29	0.38	0.41	105	108	102	103	206	222	37	32	23.3	23.5
IR78937-B-3-B-B-1	2.08	3.27	36	0.36	0.42	112	115	101	104	204	217	42	33	22.6	22.8
BR7870-5*(NIL)-8-HR4	2.52	3.61	30	0.38	0.42	112	117	94	100	226	242	39	29	21.0	21.6
BR7873-5*(NIL)-51-HR6	3.04	4.01	24	0.42	0.44	102	105	99	102	252	267	28	25	20.7	21.0
NERICA 4	2.10	2.71	23	0.36	0.35	115	118	93	98	201	215	35	33	22.3	22.7
IR64 (Check)	2.38	3.50	32	0.41	0.44	107	110	88	91	219	240	37	28	22.2	22.5
Binadhan-7 (Check)	2.60	4.16	38	0.40	0.46	112	115	91	97	249	265	41	26	22.8	23.3
BRRI dhan49 (Check)	1.36	2.52	46	0.27	0.33	126	130	96	100	235	252	61	42	22.0	22.5
Guti Swarna (L. check)	1.30	3.01	57	0.25	0.36	134	136	103	109	240	258	62	41	22.6	23.0
$LSD_{0.05}$	0.33	0.24	-	0.03	0.02	1.2	1.5	1.3	1.0	9	7	4	3	0.6	0.5
F-test	***	***	-	***	***	***	***	***	***	***	***	***	***	***	***

***P≤0.001 (Strongly significant

Table 6. Correlation coefficients among the traits of 30 genotypes under rainfed environment

Parameters	Grain yield (t ha^{-1})	Panicles m^{-2} (no.)	Sterility (%)	Grain wt. (g)	Plant ht (cm)	Biomass (t ha^{-1})	Harvest index
Wet season 2009							
Grain yield	1						
Panicles m^{-2}	0.661**	1					
Sterility (%)	-0.919**	-0.483**	1				
Grain weight	0.226*	-0.062 ns	-0.214ns	1			
Plant ht (cm)	0.206*	-0.025 ns	-0.151ns	0.310**	1		
Biomass	0.963**	0.707**	-0.831**	0.198ns	0.207ns	1	
Harvest index	0.919**	0.504**	-0.937**	0.231*	0.142ns	0.793**	1
Wet season 2010							
Grain yield	1						
Panicles m^{-2}	0.778**	1					
Sterility (%)	-0.928**	-0.689**	1				
Grain weight	0.175ns	-0.087ns	-0.059ns	1			
Plant ht (cm)	0.348**	0.160ns	-0.291**	0.312**	1		
Biomass	0.924**	0.840**	-0.854**	0.108ns	0.340**	1	
Harvest index	0.913**	0.572**	-0.851**	0.231*	0.317**	0.691**	1

*Significant at P≤0.05, **Significant at P≤0.01 and ns=not significant.

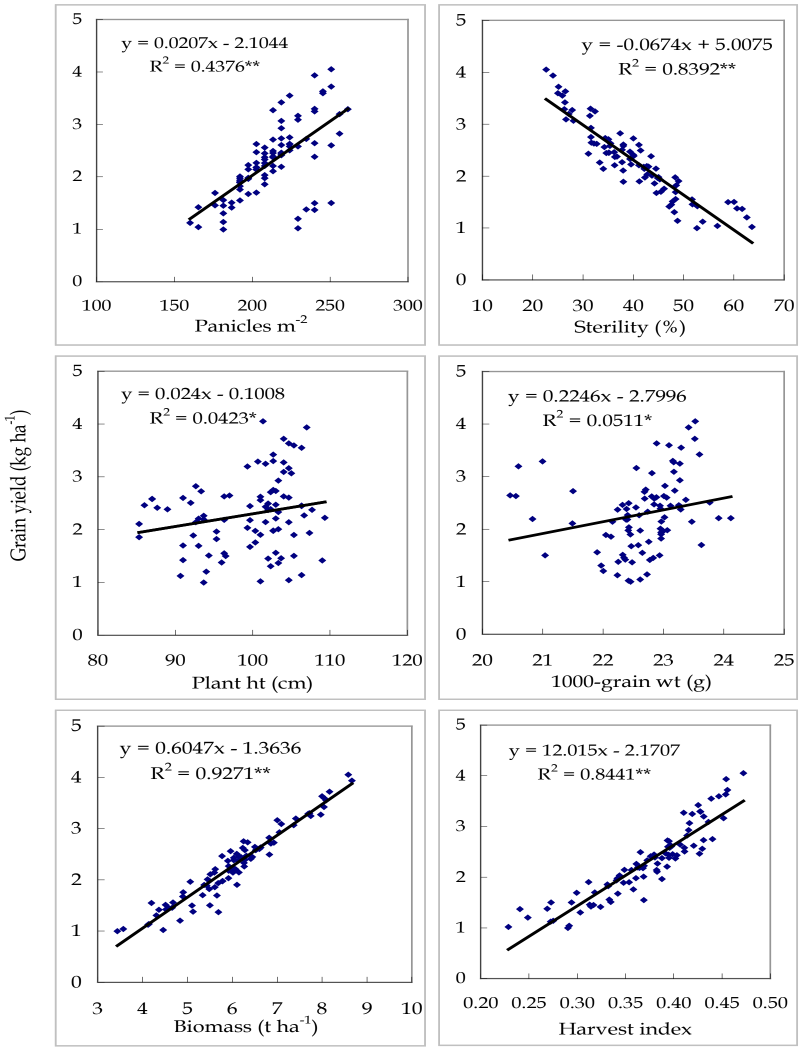


Fig.8. Relationship of grain yield and yield attributes of 30 rice genotypes under drought prone rainfed environment during 2009WS.

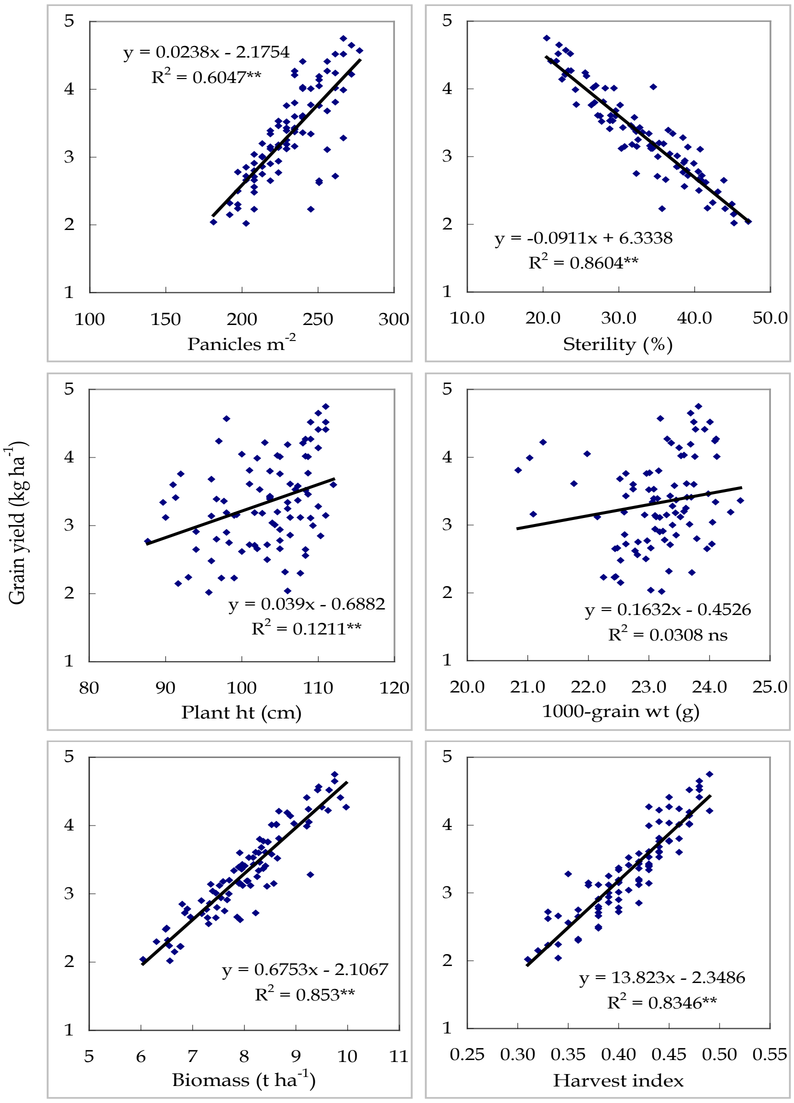


Fig. 9. Relationship of grain yield and yield attributes of 30 rice genotypes under drought prone rainfed environment during 2010WS.

Root Biomass

Root biomass varied significantly across the genotypes in both experimental years. Most of the roots of all the genotypes existed in 0 to 10 cm soil depth and, thereafter reduced the root biomass into 10 to 40 cm depth. Among the 30 rice genotypes, the highest mean root dry matter (4.21 g/0.015 cm^3) was observed in the genotype IR74371-70-1-1 which was statistically similar to NERICA 4 (4.19 g/0.015 cm^3), IR83377-B-B-93-3 (4.15 g/0.015 cm^3), IRRI 123 (4.13 g/0.015 cm^3) and IR83381-B-B-6-1 (3.80 g/0.015 cm^3) across the two seasons. (Fig. 10). Root biomass ranged from 2.05 to 4.21 g/0.015 cm^3. Thereby, the five IR74371-70-1-1, NERICA, IR83377-B-B-93-3, IRRI 123 and IR83381-B-B-6-1 found drought tolerant.

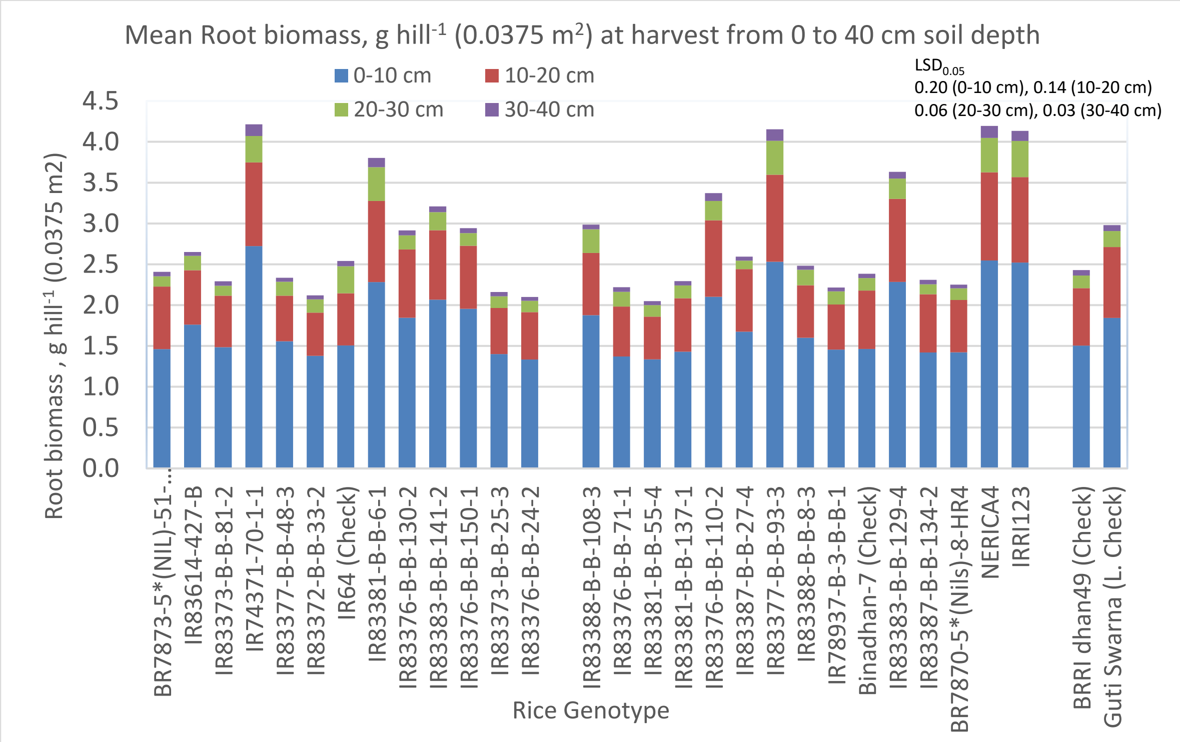


Fig. 10. Mean Root biomass, g hill^{-1} (0.0375 m^2) of the rice genotypes in 0 to 40 cm soil depth at harvest under drought prone rainfed environment during 2009 and 2010WS

Discussion

Drought stress quantifying based on rainfall, soil moisture and soil water potential

Different intensities of drought stress occurred in each season of the study, where drought severity was higher in 2009WS compared to 2010WS (Henry et al., 2011). Rainfall received by the crops of the experiments was considerably lower at the northwest region of Bangladesh (Karmakar et al., 2010). Moreover, the rains were very much unevenly distributed (Fig. 1) within the years and seasons (Haefele et al., 2006). Mean annual rainfall of the experimental years (744 and 897 mm in 2009 and 2010, respectively) were much lower than the country average 2300 mm ranged from 1000 to 5000 mm (Saleh et al., 2000; Karmakar et al., 2012). Meteorological data shows that much less rains occurred in 2009WS while 2010WS was moderately rainy (Fig. 1& 2). Consequently, the crop experienced substantial and intermittent drought stress in 2009 and 2010WS, respectively. Rainfall distribution, groundwater level (Haefele and Bouman, 2008) and soil moisture content and soil water tension (Henry et al., 2011) during reproductive phase of crop indicated a higher water stress for the trials conducted under rainfed environment. Consequently, no doubt that rainfall is an important determinant of the yield of rainfed lowland rice (Wade et al., 1998). Drought amount and duration varied in different crop stage as well as cropping years. Crop at vegetative stage did not face drought stress in both the years. However, severe drought stress existed in reproductive and ripening stage caused higher spikelet sterility (Islam and Islam, 2010) in 2009WS while it was moderate in 2010WS. Drought amount and duration was significantly higher in 2009WS than 2010WS that caused higher grain yield reduction (14 to 57%) in 2009WS over 2010WS. This result corroborates with Islam and Islam (2010) found that yield was reduced by 30 to 55% due to drought stress. Moreover, crop experienced severe drought stress with 43 drought days amounting 247 mm drought in 2009 while it was only 25 days and 107 mm in 2010, respectively. These findings are alignment with Islam et al. (2007) who reported maximum drought of 40 days and minimum drought of 22 days in northwest Bangladesh.

Genotype clustering through dendogram regarding phenotypic acceptability, leaf-rolling, leaf-drying and spikelet sterility

Dendogram of the rice genotypes showed drought stress severity that drawn based on phenotypic acceptability, leaf-rolling and leaf-drying score, and spikelet fertility. Genotypes belonging to the distant clusters maintained highest genetic variation. Genotypic variability in any crop is requirement for selection of superior genotypes over the existing cultivars (Murthy et al., 2011). The genotypes having lower inter cluster distances values in cluster I and III could be used as parents for the development of drought-resistant varieties. The other cluster (II) had the highest inter cluster mean value indicated that materials of this cluster are highly susceptible to drought. These results indicated, selection of genotype(s) from cluster III have positive impact and selection of genotype from cluster I and II have negative impact for drought resistant. It was preferential to make a decision that intra-cluster diversity was the highest in cluster I indicated more heterogeneous genotypes had in this cluster. Higher inter and intra cluster distances indicate higher genetic variability among genotypes between and within clusters, respectively. Phenotypic acceptability, leaf-rolling and leaf-drying at reproductive stage had positive impact in both the vectors. The characters that showed positive value in both vectors contributed most towards divergence. Spikelet sterility had negative impact in vector I and positive impact in vector II towards divergence. Double negative value of phenotypic acceptability at vegetative stage in vector I and II contributed lowest for divergence in the studied materials. Generally, positive value of the parameters like phenotypic acceptability, leaf rolling, leaf drying and spikelet sterility towards the vectors contributed higher for divergence while the negative value had lower contribution.

Genotypic variation on yield, yield attributes and agronomic parameters under drought stress

The tested genotypes varied significantly in respect of grain yield, yield attributes and agronomic parameters under drought stress (Murthy et al., 2011). It was might be due to the genotypic variability in response to drought stress of the genotypes (Sakai et al., 2010; Sarvestani et al., 2008). In general grain yield was lower in 2009WS compared to 2010WS as because drought stress was more in 2009WS than 2010WS. Genotypes responded differently under different drought stress conditions and habitually reduced grain yield of rainfed rice (Pantuwan et al., 2002b). Grain yield reduction varied from 14 to 57% due to drought stress across the cropping years and genotypes. Kumar et al., (2007) reported that drought stress at the flowering stage reduced yield by an average of 80% relative to a non-stressed control condition. Sarvestani et al. (2008) reported that grain yield reduced by 21, 50 and 21% due to water deficit at vegetative, flowering and grain filling stages, respectively. Yield of second year was higher than first year due to higher number of panicles m^{-2}, higher grain weight and lower spikelet sterility in 2010 compared to 2009. Genotypes performed differently in terms of yield and yield attributes under drought stress (Sakai et al., 2010). Long duration varieties like Guti Swarna and BRRI dhan49 suffered severely due to late season drought stress so that yield of these mega varieties reduced much more due to less panicle development and panicle exertion. Sarvestani et al. (2008) also found lower yield in the long duration cultivar Nemat due to late season drought. The low yield obtained in the genotypes was generally caused by a large percentage of unfilled grains per panicle due to reproductive phase drought (Wopereis et al., 1996). The main reasons for yield reduction was late season drought that were not suitable for panicle development impaired with reduced grain filling, grain number and weight (Sarvestani *et al.,* 2008; Islam et al., 1994; Bouman and Toung, 2001). Grain yield reduction resulted from greatly reduction of filled grain per panicle (Pantuwan et al., 2002a). Across the genotypes and years, harvest index fluctuated from 0.25 to 0.45 among the genotypes. These findings are in conformity with those of Fageria et al., 2010 and Kiniry et al., 2001. Harvest index varied significantly among cultivars ranging from 0.36 to 0.52 (Fageria et al., 2010) and from 0.35 to 0.62 (Kiniry et al., 2001) indicating the importance of this variable for yield stimulation. Harvest index generally was lower than the optimum level of high yielding variety in 2009 (more drought stress existed) but it was comparatively higher in 2010WS. Extremely low harvest index values related to drought stress resulted higher sterility, lower spikelet fertility, lower grain filling and lower grain weight and thereby grain yield (Haefele et al., 2003). Genotypes produced comparatively higher yield even under drought stress contained higher harvest index. These results are in accordance with Jearakongman et al. (1995) who reported that cultivars suitable for rainfed conditions are those with high yield potential resulting from high harvest index. Spikelet sterility and harvest index are the important parameters to quantify drought stress. Higher value of sterility and lower value of harvest index indicate susceptibility to drought tolerance (IRRI, 2002; Lafitte et al., 2002).

Days to flowering and maturity of almost all the genotypes in generally reduced by 1 to 5 days in 2009WS due to drought stress compared to 2010WS prevailed less drought stress. In general, time required to flowering ranged to a great extent among the genotypes and experimental years (Henry et al., 2012). Drought stress started from panicle initiation to maturity of many cultivars. However, some short duration genotypes escaped some extent this drought stress. Rainfed rice is extremely sensitive to water deficit from about 12 days before 50% flowering to about 7 days after flowering (Fischer et al., 2012). Drought stress at reproductive phase enhanced crop to reach early maturity. It happened might be due to water stress at reproductive stage forced the plant to switch over from flowering to maturity very faster. In contrast, many researchers (Sakai et al., 2008) reported that drought stress prior to flowering delayed flowering and maturity. However, Atlin et al., (2006) reported that days to flowering of high yielding rice varieties was delayed by 15 days while it was 5 days earlier for *japonica* varieties in water stressed drought prone environment than well watered condition. Plant height, panicles m^{-2}, grains panicle^{-1}, grain weight, fertility were reduced while sterility increased significantly in the severe drought year compared to less drought year. These findings are in agreement with Pantuwan *et al.,* (2002a) who reported that unfilled grain in the drought stress condition was 48% compared with 20% in well watered condition while 1000-grain weight was 18% smaller in drought stress. It happened might be due to genetically variability of the genotypes and also affected by drought stress (Fageria and Filho, 2007; Peng et al., 2000). Spikelet fertility was judged the most practical character by which to score cultivar performance (Garrity and O'Toole, 1994). It increased in comparatively less drought year 2010 over severe drought year 2009WS.

Grain yield was significantly and positively associated with all the yield attributes like panicles m^{-2}, grains panicle^{-1}, grain weight, spikelet fertility under drought stress however; spikelet sterility had negative correlation with yield

(Pantuwan et al., 2002a; Murthy et al., 2011; Yadav, 1992). Haider *et al.,* (2012) also found that thousand grain weight (0.476**), grains per panicle (0.733**), spikelet fertility (0.709**) had positive and significant association with grain yield under drought stress; whereas, spikelet sterility had significantly negative correlation with yield. Short-duration genotypes would be preferable for many drought-prone environments because this could reduce the late-season drought risk and open options for post-rice crops in favorable years (Haefele et al., 2006). However, short duration variety has limitation that could produce comparatively lower yield than the mega variety in the favorable years (Pantuwan et al., 2002a; Fischer et al., 2012). Drought resistant cultivars may be considered to be those produce higher grain yield under drought conditions (Pantuwan et al., 2002b).

Root biomass

Root biomass of the tested genotypes varied significantly across the genotypes (Fageria, 2010; Uddin et al., 2009). The highest root biomass (61.1%) of the genotypes located in the 0-10 cm soil depth followed by 10-20 cm (27.1%), 20-30 cm (8.8%) and the lowest (3.0%) was in 30-40 cm. These results are in alignment with the findings of Henry et al., 2011; Fageria, 2010; Uddin et al., 2009. That means most of the root system (88.2%) positioned to the top 20 cm of the soil layer. Similar findings also reported by Sharma et al. (1994) who found that 90% of the total root system restricted in the 0-20 cm soil depth. Some genotypes having more roots biomass extracted more water from deeper soil than others and acquired more drought tolerance.

Conclusion

Based on overall performances, the genotypes IR74371-70-1-1, NERICA4, IRRI 123, IR83377-B-B-93-3, and IR83381-B-B-6-1 were selected as drought tolerant and BR7873-5*(NIL)-51-HR6 was selected as drought escaping. From these findings, the genotypes IR74371-70-1-1 and BR7873-5*(NIL)-51-HR6 released as drought tolerant rice variety named BRRI dhan56 and BRRI dhan57, respectively through national variety release system. Rice cultivars having extensive deep root systems are proficient to mine moisture from deep soil layer indicated that more efficient in drought prone rainfed environments. Moreover, the selected genotypes could be utilized to improve varieties through classical breeding or using biotechnology linked with innovative agronomic management.

Acknowledgements

We are grateful to STRASA, IRRI, BARC and BRRI for financial support.

References

Atlin, G.N., Lafitte, H.R., Tao, D., Amante, M, Courtois, B., 2006. Developing rice cultivars for high-fertility upland systems in the Asian tropics. Field Crops Res. 97, 43-52.

BARC (Bangladesh Agricultural Research Council) 2018. Fertilizer Recommendation Guide. Published by BARC, Farm gate, Dhaka. pp. 1-257.

Bernier, J., Kumar, A., Venuprasad, R., Spaner, D., Atlin, G., 2007. A large-effect QTL for grain yield under reproductive-stage drought stress in upland Rice. Crop Sci. 47, 507-516.

Bouman, B.A.M., Toung, T.P., 2001. Field water management to save water and increase its productivity in irrigated low land rice. Agric. Water Mgt. 49(1), 11-30.

BRRI (Bangladesh Rice Research Institute) 2019. *Adhunik Dhaner Chash* (Cultivation of Modern Rice), Gazipur, Bangladesh. pp. 5-93.

Cruz, R.T., O'Toole, J.C., Dingkuhn, M., Yambao, E.B., Thangaraj, M., De Datta, S.K., 1986. Shoot and root responses to water deficits in rainfed lowland rice. Australian J. Plant Physiol. 13, 567-575.

Fageria, N.K., 2010. Root growth of the upland rice genotypes as influenced by nitrogen fertilization. In: Proceedings of the 21th World Congress of Soil Sci., 1-6 August 2010, Brisbane, Australia. pp. 120-122.

Fageria, N.K., Filho, M.P.B., 2007. Dry-matter and grain yield, nutrient uptake, and phosphorus use-efficiency of lowland rice as influenced by phosphorus fertilization. Communications in Soil Sci. Plant Analysis 38, 1289-1297.

Ferdous, M.G., Baten, M.A., 2011. Climatic variables of 50 years and their trends over Rajshahi and Rangpur Division. J. Environ., Sci. & Natural Resources 4(2), 147-150.

Fischer, K.S., Fukai, S., Kumar, A., Leung, H., Jongdee, B., 2012. Field phenotyping strategies and breeding for adaptation of rice to drought. Frontiers in Physiology 3, 1-21.

Garrity, D.P., O'Toole, J.C., 1994. Screening for drought resistance at the reproductive phase. Field Crop Res. 39, 99-110.

Gomez, K.A., 1972. Techniques for field experiments with rice. Intl. Rice Res. Inst. pp. 30-37.

Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research. John Wiley and Sons. Inc. New York. USA. pp. 97-423.

Haefele, S.M., Bouman, B.A.M., 2008. Drought prone rainfed lowland rice in Asia: Limitations and management options. In: Drought frontiers in rice: Crop improvement for increased rainfed production. Intl. Rice Res. Inst. pp. 211-226.

Haefele, S.M., Naklang, K., Harnpichitvitaya, D., Jearakongman, S., Skulkhu, E., Romyen, P., Phasopa, S., Tabtim, S., Suriya-arunroj, D., Khunthasuvon, S., Kraisorakul, D., Youngsuk, P., Amarante, S.T., Wade, L.J., 2006. Factors affecting rice yield and fertilizer response in rainfed lowlands of northeast Thailand. Field Crops Res. 98(1), 39-51.

Haefele, S.M., Wopereis, M.C.S., Ndiaye, M.K., Barro, S.E., Isselmou, M.O., 2003. Internal efficiencies, fertilizers recovery rates and indigenous nutrient supply of irrigated lowland rice in Sahelian West Africa. Field Crops Res. 80, 19-32.

Haider, Z., Khan, A.S., Zia, S., 2012. Correlation and path coefficient analysis of yield components in rice (Oryza sativa L.) under simulated drought stress condition. American-Eurasian J. Agric. Environ. Sci. 12(1), 100-104.

Henry, A., Gowda, V.R.P., Torres, R.O., McNally, K.L., Serraj, R., 2011. Variation in root system architecture and drought response in rice (*Oryza sativa*): Phenotyping of the Oryza SNP panel in rainfed lowland fields. Field Crops Res. 120, 205–214.

Henry, A., Torres, R., Holongbayan, L., 2012. Root sampling in the field with soil cores and monoliths. In: Shashidar HE, Henry A, Hardy B (Editors), Methodologies for Root Drought Studies in Rice.): Intl. Rice Res. Inst., Philippines. pp. 52-61.

Hijmans, R.J., Serraj, R., 2008. Modeling spatial and temporal variation of drought in rice production. In: Serraj R, Bennett J, Hardy B, editors. Drought frontiers in Rice: Crop Improvement for Increased Rainfed Production. World Scientific Publishing. Intl. Rice Res. Inst., Philippines. pp. 19-31.

IRRI (International Rice Research Institute) 1994: Soil and Plant Sampling and Measurements. Part-2-Plant Sampling and Management (IN6-02). Intl. Rice Res. Inst., Philippines. pp. 3-24.

IRRI (International Rice Research Institute) 2002: Standard Evaluation System for Rice. Intl. Rice Res. Philippines. pp. 1-57.

Islam, M.T., Hassanuzzaman, K.H., Khan, L.R., 2007. Drought simulation model for Aman rice cultivation in northwest region of Bangladesh. J. Agril. Engineering 33/AE, 37-42.

Islam, M.T., Islam, M.S., 2010. Effect of drought on Aman rice cultivation. J. Agril. Engineering 38/AE, 89-92.

Islam, M.T., Salam, M.A., Kauser, K., 1994. Effect of soil water stress at different growth stages of rice on yield, components and yield. Progressive Agric. 5(2), 151-156.

Jearakongman, S., Rajatasereekul, S., Naklang, K., Romyen, P., Fukai, S., Skulkhu, E., Jumpaket, B., Nathabutr, K., 1995. Growth and grain yield of contrasting rice cultivars grown under different conditions of water availability. Field Crops Res. 44, 139-150.

Kamoshita A, Babu RC, Boopathi NM, Fukai S 2008: Phenotypic and genotypic analysis of drought-resistance traits for development of rice cultivars adapted to rainfed environments. Field Crops Research 109 1–23.

Karmakar, B., Ali, M.A., Mazid, M.A., Duxbury, J., Meisner, C.A., 2004. Validation of system of rice intensification (SRI) practice through spacing, seedling age and water management. Bangladesh Agron. J. 10(1&2), 13-21.

Karmakar, B., Haefele, S.M., Ali, M.A., Ansari, T.H., Aditya, T.L., Islam, A.K.M.S., 2012. Yield and yield components of rice genotypes as affected by planting dates in drought prone environment. Bangladesh Agron. J. 15(1), 71-79.

Karmakar, B., Haefele, S.M., Aditya, T.L., Ali, M.A., Islam, M.T., Islam, M.R., 2010. Evaluation of rice germplasm under drought prone rainfed environment in northwest Bangladesh. In: Proceedings of the 3rd Intl. Rice Congress, 8-12 Nov 2010, Hanoi, Vietnam. p. 49.

Kiniry, J.R., McCauley, G., Xie, Y., Arnold, J.G., 2001. Rice parameters describing crop performance of four U. S. cultivars. Agron. J. 93, 1354–1361.

Kumar, R., Venuprasad, R., Atlin, G.N., 2007. Genetic analysis of rainfed lowland rice drought tolerance under naturally occurring stress in eastern India: heritability and QTL effects. Field Crops Res. 103, 42-52.

Lafitte, H.R., Courtois, B., Atlin, G.N., 2002. IRRI's Experience in Field Screening for Drought Tolerance and Implications for Breeding. In: Saxena NP, O'Toole JC, editors, Field Screening for Drought Tolerance in Crop Plants with Emphasis on Rice. Proceedings of the Intl. Workshop held on 11–14 December 2000 at ICRISAT, Patancheru, India. pp. 25-40.

Mackill, D.J., Coffman, W.R., Garrity, D.P. 1996. Rainfed lowland rice improvement. Intl. Rice Res. Inst. Philippines pp. 45-46.

Mahmood, R., Meo, M., Legates, D.R., Morrissey, M.L., 2003. The CERES-Rice model-based estimates of potential monsoon season rainfed rice productivity in Bangladesh. The Professional Geographer 55:2, 259-273.

Mambani, B., De Datta, S.K., Redulla, C.A., 1990. Soil physical behavior and crop responses to tillage in lowland rice soils of varying clay content. Plant Soil 126, 227-235.

Murthy, B.C.K., Kumar, A., Hittalmani, S., 2011. Response of rice genotypes under aerobic conditions. Electronic J. Plant Breeding 2(2), 194-199.

Pandey, S., Bhandari, H., 2008. Drought: economic costs and research implications. In: Serraj R, Bennett J, Hardy B, editors. Drought frontiers in Rice: Crop Improvement for Increased Rainfed Production. Intl. Rice Res. Inst. Philippines. pp. 1-17.

Pandey, S., Bhandari, H., Hardy, B., 2007. Economic costs of drought and rice farmers' coping mechanisms: a cross-country comparative analysis. Intl. Rice Research Inst., Philippines. p. 203.

Pantuwan, G., Fukai, S., Cooper, M., Rajatasereekul, S., O'Toole, J.C., 2002a. Yield response of rice genotypes to different types of drought under rainfed lowlands. Part-1. Grain yield and yield components. Field Crops Res. 73,153-168.

Pantuwan, G., Fukai, S., Cooper, M., Rajatasereekul, S., O'Toole, J.C., 2002b. Yield response of rice genotypes to drought under rainfed lowlands Part-2. Selection of drought resistant genotypes. Field Crops Res. 73, 169-180.

Peng, S., Laza, R.C., Visperas, R.M., Sanico, A.L., Cassman, K.G., Khush, G.S., 2000. Grain Yield of Rice Cultivars and Lines Developed in the Philippines since 1966. Crop Sci. 40, 307–314.

Riches, C.R., 2008. The high Barind tract: a challenging drought prone agricultural environment. In: Proceedings of the international Workshop on improving agricultural productivity in rice-based systems of the High Barind Tract of Bangladesh organized by IRRI. 4-5th March 2006. BRAC Center, Dhaka, Bangladesh. pp. 3-6.

Sakai, T., Duque, M.C., Cabrera, F.A.V., Martínez, C.P., Ishitani, M., 2010. Establishment of drought screening protocols for rice under field conditions. Acta Agronomica 59 (3), 338-346.

Saleh, A.F.M., Bhuiyan, S.I., 1995. Crop and rainwater management for increasing productivity of rainfed lowland rice systems. Agril. System 49, 259-276.

Saleh, A.F.M., Mazid, M.A., Bhuiyan, S.I., 2000. Agro-hydrologic and drought-risk analyses of rainfed cultivation in northwest Bangladesh. In: Tuong TP, Kam SP, Wade LJ, Pandey S, Bouman BAM, Hardy B, editors. Characterizing and Understanding Rainfed Environments. Int. Rice Res. Inst., Philippines. pp. 233-244.

Samson, B.K., Hasan, M., Wade, L.J., 2002. Penetration of hard-pans by rice lines in the rainfed lowlands. Field Crops Res. 76, 175–188.

Sarvestani, Z.T., Pirdashti, H., Sanavy, S.A.M.M., Balouchi, H., 2008. Study of water stress effects in different growth stages on yield and yield components of different rice cultivars. Pakistan J. Bio. Sci. 11(10), 1303-1309.

Sharma, P.K., De Datta, S.K., Redulla, C.A., 1987. Root growth and yield response of rainfed lowland rice to planting method. Expt. Agric. 23, 305-313.

Sharma, P.K., Pantuwan, G., Ingram, K.T., De Datta, S.K., 1994. Rainfed lowland rice roots: Soil and hydrological effects. In Krick GJD ed., Rice Roots: Nutrient and Water Use. Intl. Rice Res. Inst. Philippines. pp. 55-66.

Shashidhar, H.E., Gowda, H.S.V., Raveendra, G.M., Kundur, P.J., Kumar, G.N., Suprabha, N., Upadhya, P., Sonam, R., 2012. PVC tubes to characterize roots and shoots to complement field plant productivity studies. In: Shashidar HE, Henry A, Hardy B (Editors), Methodologies for Root Drought Studies in Rice.): Intl. Rice Res. Inst., Philippines. pp. 15-21.

Torres, R., Henry, A., Kumar, A., 2012. Methodologies for managed drought stress experiments in the field. In: Shashidhar HE, Henry A, hardy B (Editors), Methodologies for Root Drought Studies in Rice. Intl. Rice Res. Inst., Philippines. pp. 43-51.

Tuong, T.P., Castillo, E.G., Cabangon, R.C., Boling, A., Singh, U., 2002. The drought response of lowland rice to crop establishment practices and N-fertilizer sources. Field Crops Res. 74, 243–257.

Uddin, M.R., Wade, L.J, Pyon, J.Y., Mazid, M.A., 2009. Rooting behavior of rice cultivars under different planting methods. J. Crop Sci. Biotech. 12(1), 17-24.

Venuprasad, R., Lafitte, H.R., Atlin, G.N., 2007. Response to direct selection for grain yield under drought stress in rice. Crop Sci. 47, 285-293.

Wade, L.J., George, T., Ladha, J.K., Singh, U., Bhuiyan, S.I., Pandey, S., 1998. Opportunities to manipulate nutrient-by-water interactions in rainfed lowland rice systems. Nutrient use efficiency in rice cropping systems: Field Crops Res. 56, 11-23.

Wopereis, M.C.S., Kropff, M.J., Maligaya, A.R., Tuong, T.P., 1996. Drought-stress responses of two lowland rice cultivars to soil water status. Field Crops Res. 46, 21-39.

Yadav, R.K., 1992. Genetic variability, correlation studies and their implication in selection of high yielding genotypes of rice. Adv. Plant Sci. 5, 306-312.

Yoshida, S., 1981. Fundamentals of Rice Crop Science. Intl. Rice Res. Inst. Philippines. pp.11-56.

Lycopene and Total Phenolic Content in Fresh and Processed High-Pigment and Ordinary Tomato Fruits

Yosr Laayouni[1,2], Imen Tlili[2], Marwa Chouikhi[2,3], Hana Bouzahouane[4,5], Amina Ben Abdallah[5] and Riadh Ilahy[2]

[1]Department of Biological Sciences, Faculty of Sciences of Bizerte, Jarzouna, University of Carthage, Tunis 7021, Tunisia
[2]Laboratory of Horticulture, National Agricultural Research Institute of Tunisia (INRAT), University of Carthage, Ariana 1004, Tunisia
[3]Department of Agronomy and Plant Biotechnology, National Institute of Agronomy of Tunisia, University of Carthage, Tunis, Tunisia
[4]Department of Biology, Faculty of Nature and Life Sciences, Mohamed Cherif Messaadia University, Souk Ahras 41000, Algeria
[5]Laboratory of Environmental Biosurveillance, Department of Biology, Faculty of Sciences, Badji Mokhtar University, BP 12, El Hadjar, Annaba 23000, Algeria
[6]Laboratory of Biodiversity and Ecosystem's Pollution, Department of Biology, Chadli Benjdid, University, El Tarf, Algeria

Abstract

Recently increasing interest is being given to local tomato genotypes and landraces for their adaptation to the ongoing climatic changes. In this context, we report a comparison between the content of lycopene and total phenolics in red ripe raw tomatoes and the processed paste of two high-pigment (HLT-F81 and HLT-F82) and an ordinary (Rio Grande) tomato landrace. High-pigment tomato berries exhibited 1.82-2.37-fold higher lycopene and their processed paste exhibited also 1.70-2.10-fold higher lycopene respectively compared to the fresh berries and sauce obtained from Rio Grande. Concerning total phenolic content, high-pigment tomato berries exhibited 1.6-2.32-fold higher total phenolic content and their processed paste exhibited also 1.82-2.71-fold higher total phenolic content respective compared to the fresh berries and sauce obtained from Rio Grande. We noticed that the stability of both lycopene and total phenolic content was not affected by processing to produce tomato paste. Such results highlight the hopeful use of new high pigment lines to obtain high nutritional value products with improved beneficial effects on human health
Key Words: *Tomato, high-pigment, kandraces, lycopene, processed tomatoes*

Introduction

Tomatoes are known for their health benefits, primarily due to high carotenoid content. This study evaluates lycopene and total phenolics content in high pigment tomato and a traditional cultivar. Recognizing these variations can guide consumer decisions and improve dietary guidelines. Recent years have seen a significant rise in awareness and interest in tomato landraces and heirloom cultivars, reflected in growing publications and research globally (Corrado et al., 2014, Sacco et al., 2014, Fullana-Pericàs et al., 2019, Scarano et al., 2020, Villena et al., 2023, Negri et al., 2003, Caramante et al., 2023, Landi et al., 2023, Donso et al., 2023, Egea et al., 2023, Arias et al., 2003, Laayouni et al., 2022, 2023). This trend is driven by farmers valuing low-input and water needs of local varieties, and consumers appreciating traditional taste and health benefits (Landi et al., 2023, Egea et al., 2023). Landraces are vital repositories of genetic diversity, with unique characteristics like stress tolerance and superior taste compared to common cultivars. The local germplasm is a crucial source of desirable traits for new cultivars adapted to rapidly changing climate (Corrado et al., 2014).

Considerable differences have been noted among tomato landraces and heirlooms regarding yield, physicochemical properties, disease resistance, and particularly fruit quality. Research on older genotypes and heirlooms indicates some landraces possess higher soluble solid content and superior functional quality compared to commercial hybrids, while achieving comparable yields, especially relevant given current climate shifts (Bonilla-Barrientos et al., 2014, Ilahy et al., 2011a Ilahy et al., 2011b ,Ladewig et al., 2021; Laayouni et al., 2022, 2023). Tomato landraces have also demonstrated adaptability to various new farming systems, including aridoculture (Fullana-Pericàs et al., 2019), low-input methods (Tagiakas et al., 2022) and urban agriculture (Tihanyi et al., 2022). Although the above reported informations, data about processed products quality from such landraces and traditional tomato cultivars is really scarce. Consequently, the objective of this study was to assess the lycopene and phenolic content in fresh tomato berries and processed paste prepared from 2 high-pigment lines and one traditional tomato cultivar widely appreciated in Tunisia.

Materials and Methods

Three determinate open-pollinated cultivars were used, including two high-pigment tomato lines: 'HLT−F81', homozygous with light-responsive hp mutations hp-2dg, and 'HLT−F82', with an UHLY mutation, both selected by the National Agricultural Research Institute of Tunisia for their high-phytochemical profiles. These lines resulted from a breeding program aimed at enhancing tomato nutritional quality. One local cultivars 'Rio Grande', considered genetic resource in Tunisia, was also used. Ancient genotypes are disappearing, grown only in small areas. 'Rio Grande' was among the most cultivated in Tunisia for decades. The trials were conducted under open-field conditions during the 2021 and 2022 seasons at the National Agricultural Research Institute of Tunisia in Ariana, northern Tunisia (36°50′39″ N 10°11′30″ E), with a Mediterranean climate. In 2021 and 2022, temperatures ranged 10–25 °C and 11–27 °C, relative humidity 55–89% and 51–87%, and rainfall 1.2–56.8 mm and 0–33.8 mm, respectively. Sowing used a clay–loamy substrate with a pH of 7.72, EC of 0.19 mS/cm, and suitable mineral and organic composition. Transplanting was in double rows with 3 plants/m², spaced 40 cm and 150 cm within and between rows. Each year, genotypes were grown in three replicated plots. Irrigation used 4 L/h drippers at 40 cm intervals. Agricultural practices involved synthetic fertilization via irrigation with 190 kg N/ha, 135 kg P2O5/ha, 431 kg K2O/ha, and 75 kg MgO/ha, as outlined in Ilahy et al. (2022).

Fruit Sampling

Tomato fruits were harvested from each plant when they reached the commercially desired red-mature-ripening stage. From each block, 20–23 fresh and healthy tomatoes were selected and transported to the laboratory. Three sets of samples were prepared once the tomatoes achieved the ideal red-ripe condition. The chosen tomatoes were rinsed with deionized water, chopped into small pieces, and blended using a laboratory blender (Waring Laboratory Science, Torrington, CT, USA). The resulting homogenates were freshly analyzed for lycopene and total phenolic content to prevent nutrient degradation or oxidation.

Tomato processing:

For processing, the selected tomato fruits were washed with deionized water, cut into small pieces and homogenized in a laboratory blender (Waring Laboratory Science, Torrington, CT, US). After grinding, the tomato puree was cooked at approximately 70°C. Then, the mixture was refined, by discarding seeds and skins to obtain improved texture at the output. The mixture was refined and concentrated at 14% using a vacuum concentration ball under 65-70°C. Finally the obtained paste was stirred and homogenized to obtain the final product.

Lycopene content determination

Lycopene extraction and determination was conducted as described by (Lee 2001) and Fish et al. (2002), respectively. The method uses a mixture of hexane/ethanol/ acetone (2/1/1 by vol.) containing 0.05% butylated hydroxytoluene (BHT). During the extraction process, some precautions were taken, like working in a reduced luminosity room and wrapping glass materials in aluminium foil to avoid lycopene loss by photooxidation. For lycopene quantification, the absorbance of the hexane extract was read at 450 nm respectively using a Cecil Instruments Ltd., Cambridge, UK. Lycopene molar extinction e = 17.2* 104/M/cm in n-hexane was used for lycopene content determination. Lycopene content was expressed as mg/kg fw.

Total phenolic content determination

Total phenols were extracted as described by Martínez-Valverde et al. (2002) on triplicate independent sample of the fresh and processed sample (0.3 g). Briefly, 5 mL of 80 % aqueous methanol and 50 µL of 37 % HCl were added to each sample. The extraction was performed at 4 °C, for 2 h, under constant shaking (300 rpm). Samples were centrifuged at 10000 g for 15 min. The total phenols assay was performed by using the Folin-Ciocalteu reagent as described by Spanos and Wrolstad (1990) on triplicate 50 µL aliquots of the supernatant. The absorbance was read at 750 nm using a Cecil BioQuest CE 2501 spectrophotometer (Cecil Instruments Ltd., Cambridge, UK). The linear reading of the standard curve was from 0 to 300 µg gallic acid equivalent/mL. Results were expressed in mg of gallic acid equivalent (GAE)/kg fw. Since sugars may interfere with the total phenolic content in sample containing high sugar levels, total phenolic contents were corrected for sugar interference, according to Asami et al., (2003) using the same methodology for total phenolics quantification.

Data analysis

The statistical analysis of the data was conducted using the IBM SPSS Statistics software for Windows, Version 21.0. (IBM Corp., Armonk, NY, USA). To compare the mean values, the least significant difference (LSD) procedure was utilized, with statistical significance set at $P<0.05$.

Results and Discussion

Lycopene content

Lycopene content in tomato landraces carrying high pigment mutations such as HLT-F81 and HLT-F82 and their respective pastes showed the highest lycopene content with respect to Rio Grande fresh and processed sauce (Figure 1). High-pigment tomato berries exhibited 1.82-2.37-fold higher lycopene and their respective processed paste exhibited also 1.70-2.10-fold higher lycopene compared to the fresh berries and sauce obtained from Rio Grande. The values obtained are in line with those previously reported for open-field-grown tomato berries, ranging from 52 to 236 mg/kg fw Ilahy et al. (2011). These results are also consistent with the data from Levin et al. (2006) and Ilahy et al. (2018), who reported values attaining 440 mg/kg fw in different tomato genotypes carrying high-pigment mutations.

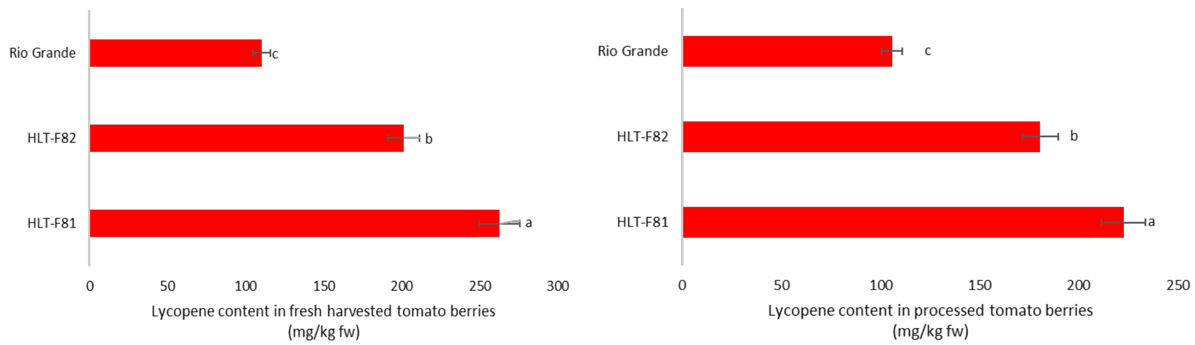


Figure 1. Lycopene content in ripe red raw berries and tomato sauce of different cv of high pigment (HLY-F81 and HLY-F82) and ordinary tomatoes (Rio Grande). The results are expressed as fresh weight (fw) Data are means ± standard deviation of three replicates.

Total phenolic content

Total phenolic content in tomato landraces carrying high pigment mutations such as HLT-F82 and HLT-F81 and their respective pastes showed the highest Total phenolic content with respect to Rio Grande fresh and processed sauce (Figure 2). High-pigment tomato berries exhibited 1.6-2.32-fold higher total phenolic content and their respective processed paste exhibited also 1.82-2.71-fold higher total phenolic content compared to the fresh berries and sauce obtained from Rio Grande. The obtained values align with those reported by various authors

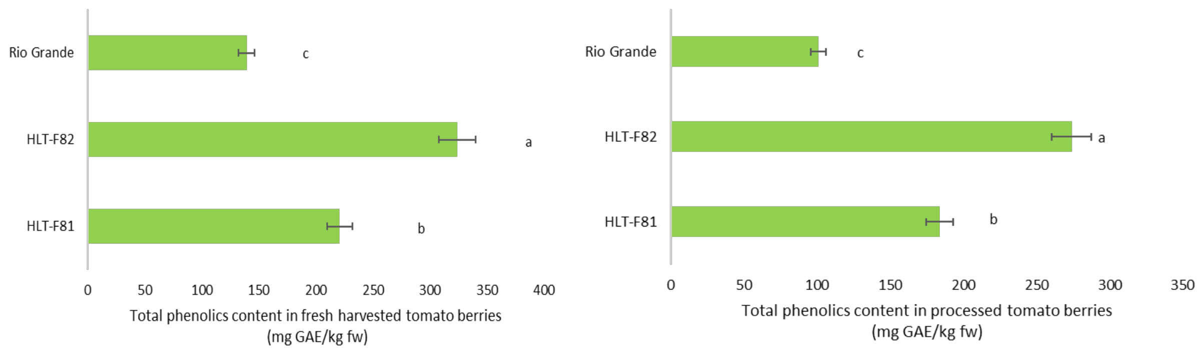


Figure 2. Total phenolic content in ripe red raw berries and tomato sauce of different cv of high pigment (HLY-F81 and HLY-F82) and ordinary tomatoes (Rio Grande). The results are expressed as fresh weight (fw) Data are means ± standard deviation of three replicates.

The higher production of secondary metabolites in high-pigment tomato lines compared to the ancient-tomato genotypes is likely associated with the hp genes carried by such lines, leading to increased plastid biogenesis (Galpaz et al., 2008), and consequently the overproduction of other metabolites generally accumulating in plastids, such as tocochromanols, vitamin C etc (Liu et al., 2004, Kolotolin et al., 2007, Bino et al., 2005). This facts leads to the attractive red-color in fresh and processed tomato products (Figure 3) from such genotytpes which increase their demand by consumers looking for functional foods and higher quality products

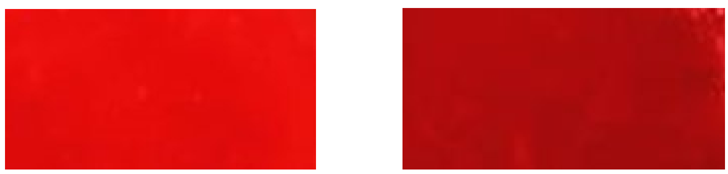


Figure 3. Color of tomato sauces obtained from ordinary (Rio Grande in light red) and high pigment (HLT-F81 in dark red) tomatoes.

Conclusion

The findings highlight the nutritional advantages of high pigment tomato cultivars, which can significantly enhance the carotenoid intake in human diets. These cultivars present opportunities for producing healthier tomato-based products, supporting improved health outcomes.

Acknowledgements

This study was kindly supported by the Ministry of Higher Education and Scientific Research of Tunisia and the Institution of Research and Agricultural Higher Education, IRESA.

References

Corrado, G., Caramante, M., Piffanelli, P., and Rao, R. (2014) Genetic diversity in Italian tomato landraces: Implications for the development of a core collection. Sci. Hortic, 168, 138–14. https://doi.org/10.1016/j.scienta.2014.01.027

Sacco, A., Ruggieri, V., Parisi, M., Festa, G., Rigano, M.M., Picarella, M.E., Mazzucato, A., Barone, A. (2015). Exploring a Tomato Landraces Collection for Fruit-Related Traits by the Aid of a High-Throughput Genomic Platform. PLoS ONE, 10, e0137139. https://doi.org/10.1371/journal.pone.0137139

Fullana-Pericàs, M., Conesa, M., Douthe, C., El Aou-ouad, H., Ribas-Carbó, M., Galmés, J. (2019). Tomato landraces as a source to minimize yield losses and improve fruit quality under water deficit conditions. Agric. Water Manag, 223, 105722. https://doi.org/10.1016/j.agwat.2019.105722

Scarano, A., Olivieri, F., Gerardi, C., Liso, M., Chiesa, M., Chieppa, M., Frusciante, L., Barone, A., Santino, A., Rigano, M.M. (2020). Selection of tomato landraces with high fruit yield and nutritional quality under elevated temperatures. J. Sci. Food Agric, 100, 2791–2799. https://doi.org/10.1002/jsfa.10312

Villena, J., Moreno, C., Roselló, S., Beltrán, J., Cebolla-Cornejo, J., Moreno, M.M. (2023). Breeding tomato flavor: Modeling consumer preferences of tomato landraces. Sci. Horti, 308, 111597. https://doi.org/10.1016/j.scienta.2022.111597

Negri, V. (2003). Landraces in central Italy: Where and why they are conserved and perspectives for their on-farm conservation. Genet. Resour. Crop Evol, 50, 871–885

Caramante, M., Rouphael, Y., Corrado, G. (2023). Genetic diversity among and within tomato (Solanum lycopersicum L.) landraces grown in Southern Italy. Genet. Resour. Crop Evol, 1–10. https://doi.org/10.1007/s10722-023-01613-9

Landi, S., Punzo, P., Nurcato, R., Albrizio, R., Sanseverino, W., Cigliano, R.A., Giorio, P., Fratianni, F., Batelli, G., Esposito, S., et al. (2023). Transcriptomic landscape of tomato traditional long shelf-life landraces under low water regimes. Plant Physiol. Biochem, 201, 107877. https://doi.org/10.1016/j.plaphy.2023.107877

Donoso, A., Salazar, E. (2023). Yield components and development in indeterminate tomato landraces: An agromorphological approach to promoting their utilization. Agronomy, 13, 434. https://doi.org/10.3390/agronomy13020434

Egea, I., Estrada, Y., Faura, C., Egea-Fernández, J.M., Bolarin, M.C., Flores, F.B. (2023). Salt-tolerant alternative crops as sources of quality food to mitigate the negative impact of salinity on agricultural production. Front. Plant Sci, 14, 1092885. https://doi.org/10.3389/fpls.2023.1092885

Bonilla-Barrientos, O., Lobato-Ortiz, R., García-Zavala, J.J., Cruz-Izquierdo, S., Reyes-Lopez, D., Hernandez-Leal, E., Hernandez-Bautista, A. (2014). Agronomic and morphological diversity of local kidney and bell pepper-shaped tomatoes from Puebla and Oaxaca, México. Rev. Fitotec. Mex, 37, 129–139. https://doi.org/10.35196/rfm.2014.2.129

Ilahy, R., Hdider, C., Lenucci, M.S., Tlili, I., Dalessandro, G. (2011). Antioxidant activity and bioactive compound changes duringfruit ripening of high-lycopene tomato cultivars. J. Food Compos. Anal, 24, 588–595. https://doi.org/10.1016/j.jfca.2010.11.003

Ilahy, R., Hdider, C., Lenucci, M.S., Tlili, I., Dalessandro, G. (2011). Phytochemical composition and antioxidant activity of high-lycopene tomato (Solanum lycopersicum L.) cultivars grown in Southern Italy. Sci. Hortic, 127, 255–261. https://doi.org/10.1016/j.scienta.2010.10.001

Ladewig, P., Trejo-TéLlez, L.I., Servin-Juarez, R., Contreras-Oliva, A., Gomez-Merino, F.C. (2021). Growth, yield and fruit quality of Mexican tomato landraces in response to salt stress. Not. Bot. Horti Agrobot. Cluj-Napoca, 49, 12005. https://doi.org/10.15835/nbha49112005

Tagiakas, R.I., Avdikos, I.D., Goula, A., Koutis, K., Nianiou-Obeidat, I., Mavromatis, A.G. (2022). Characterization and evaluation of Greek tomato landraces for productivity and fruit quality traits related to sustainable low-input farming systems. Front. Plant Sci, 13, 994530. https://doi.org/10.3389/fpls.2022.994530

Romdhane, A., Riahi, A., Ujj, A., Ramos-Diaz, F., Marjanović, J., Hdider, C. (2023). Comparative Nutrient and Antioxidant Profile of High Lycopene Variety with hp Genes and Ordinary Variety of Tomato under Organic Conditions. Agronomy, 13, 649. https://doi.org/10.3390/agronomy13030649

Tihanyi, A., Csambalik, L. (2022). Motivations of small-scale producers and gardeners towards tomato landrace utilization. Rev. Agric. Rural. Dev, 11, 176–180. https://doi.org/10.14232/rard.2022.1-2.176-180

Levin, I., De Vos, C.R., Tadmor, Y., Bovy, A., Lieberman, M., Oren-Shamir, M., Segev, O., Kolotilin, I., Keller, M., Ovadia, R., et al. High pigment tomato mutants—More than just lycopene (a review). (2006). Isr. J. Plant Sci, 54, 179–190. https://doi.org/10.1560/ijps_54_3_179

Ilahy, R., Siddiqui, M.W., Tlili, I., Montefusco, A., Piro, G., Hdider, C., Lenucci, M.S. (2018). When color really matters: Horticultural performance and functional quality of high-lycopene tomatoes. Crit. Rev. Plant Sci, 37, 15–53. https://doi.org/10.1080/07352689.2018.1465631

Galpaz, N., Wang, Q., Menda, N., Zamir, D., Hirschberg, J. (2008) Abscisic acid deficiency in the tomato mutant high-pigment 3 leading to increased plastid number and higher fruit lycopene content. Plant J, 53, 717–730. https://doi.org/10.1111/j.1365-313x.2007.03362.x

Liu, Y., Roof, S., Ye, Z., Barry, C., Van Tuinen, A., Vrebalov, J., Bowler, C., Giovannoni, J. (2004). Manipulation of light signal transduction as a means of modifying fruit nutritional quality in tomato. Proc. Natl. Acad. Sci. USA, 101, 9897–9902. https://doi.org/10.1073/pnas.0400935101

Bino, R.J., Ric de Vos, C.H., Lieberman, M., Hall, R.D., Bovy, A., Jonker, H.H., Tikunov, Y., Lommen, A., Moco, S., Levin, I. (2005). The light-hyperresponsive high pigment-2dg mutation of tomato: Alterations in the fruit metabolome. New Phytol, 166, 427–438. https://doi.org/10.1111/j.1469-8137.2005.01362.x

Kolotilin, I., Koltai, H., Tadmor, Y., Bar-Or, C., Reuveni, M., Meir, A., Nahon, S., Shlomo, H., Chen, L., Levin, I. (2007). Transcriptional profiling of high pigment-2dg tomato mutant links early fruit plastid biogenesis with its overproduction of phytonutrients. Plant Physiol, 145, 389–401. https://doi.org/10.1104/pp.107.102962

Laayouni, Y., Tlili, I., Henane, I., Ali, A. B., Égei, M., Takács, S., ... & Ilahy, R. (2023). Phytochemical profile and antioxidant activity of some open-field ancient-tomato (Solanum lycopersicum L.) genotypes and promising breeding lines. Horticulturae, 9(11), 1180. https://doi.org/10.3390/horticulturae9111180

Laayouni, Y., Riadh, I., Tlili, I., Ali, A. B., & R'him, T. (2022). Genotypic differences affecting biometric, processing and functional quality attributes in tomato fruits. Turkish Journal of Agriculture-Food Science and Technology, 10(8), 1390-1394. https://doi.org/10.24925/turjaf.v10i8.1390-1394.4947

Asami, D. K., Hong, Y. J., Barrett, D. M., & Mitchell, A. E. (2003). Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry, and corn grown using conventional, organic, and sustainable agricultural practices. Journal of agricultural and food chemistry, 51(5), 1237-1241.

Use of ICT and Social Media Platforms for Accessing Agricultural Information Among Poultry Farmers in Jos South Local Government Area, Plateau State, Nigeria

Vihi, S.K[1*]., Abdullahi, S[2]., Binuyo, G[1]., Jesse, B[3] and Owa, G.T[1]

[1]Department of Agricultural Extension & Management, Federal College of Forestry, Jos Plateau State, Nigeria
[2]Montane Forest Research Station Jos, Plateau State, Nigeria

[3]Federal College of Forest Resources Management Maiduguri, Borno State, Nigeria
Corresponding Author: vihisam@gmail.com

Abstract

This study examined the use of Information and Communication Technology (ICT) and social media for accessing agricultural information among poultry farmers in Jos South Local Government Area, Plateau State, Nigeria. The objective is to assess the extent to which these tools are utilized and the factors influencing their adoption. The study employed a descriptive survey design, collecting data from 136 poultry farmers. The findings reveal that 88% of farmers frequently use mobile phones, while 73% utilize social media platforms, particularly Facebook (mean = 2.76) and WhatsApp (mean = 2.71). Factors such as age (negative coefficient: -1.2068), education (positive coefficient: 0.0958), household size (negative coefficient: -0.0538), stock size (positive coefficient: 8.6964), and annual income (positive coefficient: 1.2086) significantly influence ICT adoption. Constraints identified include inadequate extension support (66%), poor internet connectivity (64%), high costs (43%), and low digital literacy (42%). The study concludes that while ICT and social media have great potential to improve poultry farming practices, several barriers need to be addressed to maximize their benefits.
Keywords: *ICT, social media, agricultural information, poultry farmers.*

Introduction

Sustainable agricultural development cannot be achieved successfully without accurate and up-to-date information and technologies to cope with globalization and its simultaneous rapid technological changes. This is because information is important for the development of any society and success for human endeavor (Sokoya et al., 2014). According to Tiwari and Sharma (2015), information is considered the fifth human need after air, water, food and shelter. Agricultural information refers to data, knowledge, and advice that is relevant to farming activities and agricultural practices. This information is essential for farmers to make informed decisions about crop production, livestock management, pest and disease control, market trends, and other aspects of agriculture. Access to timely and accurate agricultural information helps farmers improve their productivity, adapt to changing conditions, and make better economic decisions. Therefore, the concept of agricultural information in general and in particular, as a source of development, is of great importance in the contemporary world and cannot be overemphasized (Ogbonna and Aguvu, 2013).

In recent years, Information and Communication Technology (ICT) and social media platforms have emerged as key tools for bridging agricultural information search gap. There is hardly an area of human activity today that has not been touched by dramatic changes in information and communication technologies (ICT). The rapid advancements in Information and Communication Technology (ICT) have revolutionized various sectors globally, including agriculture. Ozor and Madukwe (2009) conceived ICT as a set of technologies that facilitate the processing, storage, retrieval and transmission of information. Information and communication technologies can be broadly defined as technologies that simplify communication, through the process and transmission of information through electronic media (Suleiman et al., 2015). Adepetun (2012) sees ICT as an essential tool and essential spice for sustainable development, which has the potential to reduce poverty and improve livelihoods by providing timely knowledge to users, reducing transaction costs and improving productivity. Social media on the other hand refer to a website or internet service that allows users to interact with each other and create content instantaneously. They are wide range of internet-based and mobile services that allow users participate in online exchanges, contribute user-created content or join online communities (Michael, 2012). The evolution of social media provided a visible solution to the challenge of information gap that hinders improvement of standard of living of people and achievement of development (Ministry of Agriculture (MOA), 2013). This is premised on the fact that social media enable blogging, tagging, discussion, networking, and so on and help to transfer information to large audiences at the same time and at a cheaper rate (Sokoya *et al.*, 2012). Social media have long been used in agriculture for facilitating communication among stakeholders, especially extension personnel (Sophie, 2013). According to Italie (2015) social media is the most recent form of digital communication and on a global scale accessing news through it by using mobile devices is gaining popularity. Within a few years, it has completely changed communication globally (Suchiradipta and Saravanan, 2016) and has become extremely popular because it allows people to connect in the online world to form a group, a forum and a community where ideas and information can be exchanged without any geographical barrier (Chui, et.al, 2012). They have impacted global development making people more informed and aware. A study conducted by Balkrishna and Deshmukh, (2017) revealed some benefits of social media in agriculture such as prompt response to questions relating to the field, saves time and cost of communication, provision of right information and at the right time like weather report, disease control, etc. Unfortunately, farmers, extension agents and other stake holders in agriculture may not be familiar with these benefits of social media.

Statement of the Problem

Information and Communication Technology (ICT) has been instrumental in enhancing agricultural productivity worldwide by facilitating access to real-time information, improving decision-making, and providing platforms for knowledge sharing. In Nigeria, the role of ICT is increasingly becoming crucial in the agricultural sector, especially in poultry farming. Poultry farmers require up-to-date information on areas such as disease management, feed formulation, and market conditions to optimize their productivity. ICT tools such as mobile phones, the internet, and social media platforms like WhatsApp and Facebook are increasingly being used as alternative sources of agricultural information for farmers (Aker, 2011). Social media platforms have emerged as dynamic tools for disseminating information in the agricultural sector. Farmers, including poultry farmers, are now using these platforms to interact with peers, extension workers, and agricultural experts. The timely access to information provided by ICT tools and social media helps to bridge the information gap left by traditional extension services (Ferris et al., 2008). However, despite the growing importance of ICT and social media platforms in agricultural information dissemination, there is limited empirical data on their usage among poultry farmers in Jos South Local Government Area. Many farmers continue to rely on traditional sources of information, such as interpersonal communication or extension services, which may not be timely or comprehensive enough to meet their needs. This creates a knowledge gap that can hinder productivity and limit farmers' ability to adapt to changing agricultural conditions. Furthermore, issues such as poor digital literacy, lack of access to reliable internet connectivity, and the high cost of technology may prevent farmers from fully utilizing ICT and social media tools. Without a clear understanding of these constraints and the factors that influence adoption, efforts to promote the use of digital platforms for agricultural development may not achieve the desired impact.

Objectives of the Study

The broad objective of the study is to examine the use of information and communication technology (ICT) and social media for accessing agricultural information among poultry farmers in Jos South Local Government Area, Plateau State, Nigeria. The specific objectives are to:

1.describe the socio-economic characteristics of poultry farmers in Jos South Local Government Area;

2.assess the level of use of ICT and social media for accessing agricultural information by poultry farmers in the study area;

3.determine the factors influencing the use of ICT and social media for accessing agricultural information by the poultry farmers and

4.identify the constraints to use of ICT and social media by the poultry farmers.

Materials And Methods

Study Area

The study was carried out in Jos South Local Government Area of Plateau State, Nigeria which is geographically located between latitude 9^0 30^0 to 10^0N and longitude 8^0 30’E of the Greenwhich meridian. It is situated at the north western part of the state with its headquarters at Bukuru, which is about 15 km from the state capital, Jos. The local government area has four districts: Du, Gyel, Kuru and Vwang districts. The Local government has a population of 650,835 (National Population Commission, NPC 2006) with an average land area of 1, 037km2. It is bounded by Barkin –Ladi Local government to the South, Riyom Local government to the South West, Jos-East Local government to the East and Bassa Local government to the West. It is known for its cold and rocky nature due to its high altitude of over 1450 meters above sea level. The coldest period is between November and February, with an average daily temperature of 18^0C while warmer periods occur between March and April. The rains fall between May and October, with a peak in August. The mean annual rainfall varies between 137.75cm and 146.0cm. The Local Government is a semi-urban location but served with vast agricultural land, with mining ponds readily supplying water for irrigation.

The common food crops grown include Rice, Maize, Irish potatoes, Yam, Acha, Sweet potatoes, Cocoyam, Tomatoes, Groundnut and assorted Vegetables. Cattle, sheep, goats, Pigs and poultry are reared by many households.

Sampling Technique

The population for this study consists of all the registered poultry farmers in all the four district of Jos South Local Government Area. They include: Gyel, Du, kuru, and Vwang districts.

The official sample frame of poultry farmers in the study area could not be obtained from either the Poultry Association of Nigeria (PAN) or the Plateau Agricultural Develpoment Programme as the presumed number obtained was too small to constitute the sample size for the study. Consequently, a reconnaissance survey was conducted in the study area where poultry farmers' who benefitted from agricultural credit were purposively enumerated. Due to the limited number of credit beneficiaries, only a total of 136 beneficiaries was obtained and consequently used as the sample size for the study. Data were collected based on the objectives of the study.

Primary data is the main source of information for this study. The data were collected through the administration of questionnaires and oral interview. The questionnaire was designed in line with the objectives of the study.

Method of Data Analysis

Both descriptive and inferential statistics were used to analyze the data. Descriptive statistics (i.e. frequency counts, percentages, mean, Likert scale) and Logit regression were used to achieve objectives of the study. Descriptive statistical tools such as frequency distribution, percentages, mean score, four point Likert type scale were used while the inferential statistical tool used was binary logit regression. Objectives 1and 4 (Socio-economic characteristics of the farmers and constraints to ICT use) were analyzed using descriptive statistical tools such as frequency distribution, percentage and mean.

Model Specification

Four poin Likert scale

Four point Likert scale was used to measure the level of ICT use among the farmers. Likert scale is a descriptive statistics tool commonly used to measure attitudes, opinions or perceptions by asking respondents to express their level of agreement or frequency regarding a particular statement. Likert scales allow for the quantification of subjective experiences and attitudes, which are then interpreted numerically to categorize responses.

The level of ICT use was measured using four-point Likert-type scale with the following options:

Frequently used = 4
Occasionally used = 3
Rarely used = 2
Never Used = 1

The mean score was calculated by dividing the total score by the number of scale points: i.e.

$4+3+2+14/2 = 2.5$

ICTs with a mean score of 2.5 or above were considered to be used by the farmers, while those below 2.5 were considered not used.

Logit Regression Model

Use of ICT in accessing agricultural information among farmers was measured using a binary, categorical variable taking up the value of 1 for ICT use, and 0 for non-use of ICT. Since the dependent variable (use of ICT) is dichotomous, its relationship with the independent variables (factors) was estimated using a binary logistic regression model. The logit model is specified as:

$Lny = Ln (p/1 - p)$

$Ln (p/1 - p) = f (\beta iXi) + ei$

Where;

Y = Level of use of ICT (1= use, 0 = otherwise)
P = Probability of ICT use in arable crop production
1 – P = probability of non-use of ICT in arable crop production
Ln = Natural logarithm function.
β_i = vector of logistic regression coefficients.
X_1 = Age of respondent (Years)
X_2 = Gender (1 if male, 2 female)
X_3 = Marital status (Yes= 1, No= 0)
X_4 = Educational level (Years of formal education)
X_5 = Household size (number of persons)
X_6 = Farming experience (years)
X_7 = Stock size (number of birds)

X_8 = Annual income (Naira)

Results And Discussion

Socio-economic characteristics of Poultry Farmers'

The age distribution shows that the majority of poultry farmers (51%) fall within the 41-50 age group, with a mean age of 42 years. This indicates that the majority of farmers are middle-aged, a demographic that may face challenges in adopting new technologies such as ICT and social media. Older farmers may be less familiar with technology compared to younger generations. However, with appropriate training and support, they can still benefit from ICT for accessing agricultural information. Since only 8% of farmers are younger (21-30 years), there may be a need to attract younger individuals into poultry farming and provide them with the necessary skills to leverage ICT for farming activities. This is consistent with Msoffe *et al*. (2010), who also reported that middle-aged farmers tend to dominate the agricultural sector but may face challenges adopting ICT tools due to unfamiliarity. However, Olaniyi (2013) indicated that younger farmers (21-30 years) are more likely to adopt new technologies like ICT, suggesting a need to engage younger individuals in poultry farming to enhance ICT use.

The table reveals that poultry farming in the study area is heavily male-dominated, with 86% of the farmers being men and only 14% women. This suggests that men are more engaged in poultry farming in the area. Gender-specific challenges may affect how ICT and social media are utilized, especially by female farmers who often face greater barriers to technology access, such as lower digital literacy, fewer financial resources, and limited autonomy in decision-making. Targeted interventions to empower female poultry farmers with digital tools and training will be crucial in ensuring equitable access to ICT. The gender distribution, with 86% male farmers, mirrors findings by Adebayo (2017), who highlighted male dominance in farming due to social and cultural roles. However, Samansiri and Wanigasundera (2014) emphasized that female farmers often face barriers to accessing ICT, including digital illiteracy and limited decision-making power, which agrees with the current study's implication for targeted interventions for women.

The vast majority of farmers (89%) are married, which reflects the typical structure of rural farming communities, where family labor is often utilized. Larger families may have younger members who are more tech-savvy and could assist in adopting ICT tools for accessing agricultural information. However, for some families, financial pressures may limit their ability to invest in smartphones or internet services necessary for effective ICT use. This result aligns with Omotayo (2005), who noted that rural communities often rely on family labor, influencing household farming practices. Married individuals may have access to younger family members who are more technologically literate, aiding ICT adoption in line with Arokoyo (2005), who emphasized the role of family in technology transfer.

Education plays a significant role in the ability to access and utilize ICT. The table shows that a high percentage of poultry farmers (51%) have tertiary education, while 45% have secondary education. This relatively high educational level suggests that many farmers possess the literacy and skills needed to navigate ICT platforms and social media. Farmers with higher education are more likely to adopt ICT for accessing agricultural information, which can improve their farming practices and market opportunities. Conversely, the small percentage of farmers with only primary education (4%) might struggle to adopt technology, indicating a need for specialized training for less educated farmers. Olaniyi (2013) similarly found that higher educational attainment positively correlates with ICT adoption, as educated farmers are more capable of navigating digital platforms. This supports Tweeten (2014), who concluded that education is a critical factor in using ICT for agricultural purposes.

The majority of farmers (65%) have household sizes between 1-5 members, while 27% have 6-10 members. Household size may influence the capacity for labor in poultry farming and also affect financial decisions regarding ICT investments. Larger households may have younger members who can assist in using ICT, but they also place greater demands on household resources, which could limit access to technology. Providing affordable ICT solutions would be beneficial for farmers with larger households. A mean household size of 5 persons aligns with Otunaiya *et al*. (2015), who reported similar household sizes among poultry farmers in Oyo State. Larger households can benefit from younger members assisting with ICT tools, but financial pressures may limit technology investments, as noted by Baye (2016).

Nearly half of the poultry farmers (47%) have between 6-10 years of farming experience, and 26% have 11-15 years. The farmers have 9 years experiences on average. This indicates a relatively experienced workforce, which may benefit from ICT tools for enhancing productivity and accessing market information. However, experienced farmers may be resistant to adopting new technologies if they are accustomed to traditional methods. Demonstrating the benefits of ICT in poultry farming through training and extension services can help overcome this barrier. This is consistent with Msoffe *et al*. (2010), who found that farmers with medium-level experience are more open to adopting

ICT if they see direct benefits. However, Omotayo (2005) pointed out that highly experienced farmers may resist new technologies due to comfort with traditional methods.
The result shows that most poultry farmers in the study are engaged in medium-scale operations, with 29% managing 1501-2000 birds and 26% managing 1001-1500 birds. These farmers are well-positioned to benefit from ICT tools that aid in disease management, feed optimization, and market insights. Farmers with smaller flocks (500-1000 birds) may face challenges in investing in ICT due to limited resources, emphasizing the need for affordable ICT solutions and microfinance support. The mean flock size is 1658 birds, reflecting a medium-scale poultry farming demographic. The predominance of medium-scale farmers with 1501-2000 birds mirrors findings from Falola et al. (2021), who observed that medium-scale poultry farmers are the most likely to adopt ICT for disease management and feed optimization due to the scale of their operations. Smaller farmers may struggle to afford ICT, similar to findings by Adebayo (2017).
The data in Table 8 provides a distribution of respondents based on their annual farm income, showing that a significant proportion of the respondents earn between 201,000–300,000 Naira annually. Specifically, 38% of respondents earn between 201,000–250,000 naira, 33% earn between 251,000–300,000 Naira, smaller proportions earn either below 200,000 Naira or more than 300,000 Naira. The mean annual income is 246,176 Naira, which is within the 201,000–250,000 Naira range, indicating that most poultry farmers fall within a middle-income category. The income levels suggest that most farmers may have a modest financial capacity, which could impact their ability to afford sophisticated ICT devices like smartphones, computers, and the internet. While social media platforms like WhatsApp and Facebook are often affordable, the cost of regular data subscriptions may still be a challenge for those in the lower income brackets (below 200,000 Naira annually). Farmers with higher incomes (above 300,000 Naira) might have more flexibility in investing in ICT tools for agricultural information access. Most respondents fall into a middle-income category (201,000-300,000 Naira), comparable to Ololade and Olagunju (2013), who noted that income level significantly influences farmers' ability to invest in ICT tools. Baye (2016) also highlighted that farmers in higher income brackets can more easily afford sophisticated ICT devices.
All the farmers (100%) are members of a cooperative or poultry association. This is a positive indicator as such associations can facilitate access to ICT training and support services. Associations also provide a platform for farmers to share information, including on ICT tools and applications that can benefit their poultry operations. All respondents belong to a cooperative, aligning with Ololade and Olagunju (2013), who stressed the importance of associations in facilitating access to ICT training and financial resources. Adebayo (2017) also highlighted that membership in agricultural cooperatives enhances the likelihood of technology adoption due to shared knowledge.
The table shows that only 27% of the farmers have regular contact with extension services, which implies that the majority (73%) lack access to professional agricultural advice and information. This represents a significant barrier to the utilization of ICT, as extension services are often key channels for introducing and training farmers on new technologies. Enhancing the reach of extension services through ICT-based platforms, such as mobile apps and social media, could improve the dissemination of agricultural information and increase technology adoption among poultry farmers. This finding aligns with Msoffe *et al*. (2010), who reported limited access to extension services in rural areas. This lack of contact poses a barrier to ICT adoption, as emphasized by Arokoyo (2005), who stressed the critical role of extension services in promoting new technologies.

Table 1 Distribution of Poultry Farmers according to socio-economic characteristics

Variable	Frequency	Percentage	Mean
Age			
21-30	11	8.0	
31-40	38	28.0	
41-50	69	51.0	
>50	18	13.0	**42**
Gender			
Male	117	86.0	
Female	19	14.0	
Marital status			
Married	121	89.0	
Single	15	11.0	
Educational level			
Primary	6	4.0	
Secondary	61	45.0	
Tertiary	69	51.0	

Household size			
1-5	88	65.0	
6-10	37	27.0	
>10	11	8.0	**5**
Farming experience			
< 5	28	21.0	
6-10	64	47.0	
11-15	36	26.0	
>15	8	6.0	**9**
Stock size (No. of Birds)			
500- 1000	26	19.0	
1001-1500	35	26.0	
1501-2000	40	29.0	
2001-2500	16	12	
2501-3000	11	8	
>3000	8	6.0	**1658**
Annual farm income			
100,000- 150,000	9	7.0	
151,000-200,000	13	9.5	
201,000-250,000	52	38.0	
251,000-300,000	45	33.0	
>300,000	17	12.5	**246,176**
Membership			
Yes	86	63.0	
No	50	37.0	
Contact			
Yes	37	27.0	
No	99	73.0	

Source: Field survey (2025)

Level of Use of ICT and Social media Platforms by Crop Farmers

The data in Table 10 provides insights into the level of Information and Communication Technology (ICT) and social media use among poultry farmers. The facilities and platforms are categorized into conventional ICTs and social media platforms, with usage measured on a scale ranging from "Frequently Used" (FU) to "Never Used" (NU). The mean score of each facility or platform is calculated, with a score of 2.5 or above indicating significant usage. The result shows that radio (mean = 3.18) and mobile phones (mean = 3.08) are the most frequently used ICT tools among poultry farmers, indicating their importance in accessing agricultural information. The finding aligns with findings by Olaniyi (2013) and Adebayo (2017), who both emphasized the widespread use of mobile phones for accessing agricultural information. Similarly, Msoffe *et al*. (2010) noted that mobile phones are essential for communication between farmers and extension agents. Television (mean = 2.41) and print media (mean = 2.18) are less commonly used. Among social media platforms, Facebook (mean = 2.76) and WhatsApp (mean = 2.71) are widely used, reflecting their growing role in connecting farmers with information and networks. This result is consistent with Falola *et al*. (2021), who found these platforms to be critical for real-time communication and marketing. YouTube (mean = 1.86) is not as popular, likely due to data and internet constraints. This is in support of Baye (2016) who indicated that high data costs and poor internet connectivity limit YouTube's use.

Platforms like Twitter (X), Instagram, Tiktok, LinkedIn, and Telegram have minimal or no use, with mean scores below 1.5, indicating they are not relevant to farmers' needs. The minimal or non usage of platforms like Twitter, Instagram, and LinkedIn mirrors findings by Adebayo (2017), who reported that these platforms are seen as less relevant for agricultural purposes due to their focus on visual and professional networking rather than practical farming information. The findings highlight that conventional ICTs, particularly radio and mobile phones, remain vital for information dissemination. Facebook and WhatsApp provide interactive platforms for farmer communication, while the underuse of YouTube suggests potential for increased adoption with improved access. Twitter, Instagram, and similar platforms are not seen as useful for poultry farmers currently.

Table 2: Level of ICT and Social media use by Poultry Farmers (N=136)

ICT facilities	**FU(4)**	**OU(3)**	**RU(2)**	**NU (1)**	**Sum**	**Mean($\bar{x}$)**

Conventional ICTs						
Radio	216	77	34	6	433	3.18*
Mobile Phone	161	213	38	5	420	3.08*
Television	108	75	122	23	328	2.41
Print media	44	93	132	28	297	2.18
Social media platforms						
Facebook	136	189	22	28	375	2.76*
WhatsApp	116	138	106	8	368	2.71*
Youtube	20	33	152	44	249	1.86
Twitter (X)	0	0	44	114	158	1.16
Instagram	0	0	0	136	136	1.0
Tiktok	0	0	0	136	136	1.0
Linkdin	0	0	0	136	136	1.0
Telegram	0	0	0	136	136	1.0

FU= frequently used, OU= occasionally used, RU= rarely used, NU = never used

Note: Mean score of 2.5 or above = used

Mean score below 2.5 = not used.

Factors Influencing ICT and Social Media Use among the Poultry Farmers

This table presents the results of a binary logit regression analysis to identify the factors influencing poultry farmers' use of ICT and social media platforms for accessing agricultural information. The constant (16.8951, P = 0.011) is statistically significant at 5% level, meaning that, when all other factors are held constant, the model predicts a baseline positive likelihood of ICT and social media usage for agricultural information access. The large coefficient suggests that even without considering the specific characteristics of the farmers, there is a strong underlying propensity for ICT use in this context. The pseudo R-squared indicates that about 16.54% of the variation in the use of ICT and social media platforms is explained by the independent variables in the model. While not a high value, it suggests the model has a moderate explanatory power. The results indicate that age, educational status, household size, stock size and annual income are significant factors influencing the use of ICT and social media for accessing agricultural information.

Age (X_1): Age coefficient is negative (-1.2068) and statistically significant at 5% level. This implies that for every additional year in age, the likelihood of using ICT decreases. It suggests that younger individuals are more likely to use ICT and social media, possibly due to greater familiarity and ease of technology adoption. It is often thought that younger people are more tech-savvy. The negative relationship between age and ICT use supports Msoffe *et al*. (2010)**,** who found younger farmers more likely to adopt ICT due to higher familiarity with technology. Asadu *et al.* (2013) also observed that younger extension workers are better at using ICT for communication, reinforcing the idea that younger individuals are more tech-savvy.

Educational status (X_4): The Coefficient of educational status is positive (0.0958) at 10% level suggesting that more educated individuals are more likely to use ICT and social media for agricultural information. This is in line with the expectation that higher education levels increase digital literacy, which facilitates the adoption of ICT. The positive relationship between education and ICT use confirms Olaniyi (2013) and Baye (2016)**,** both of whom identified higher education as a key factor in increasing digital literacy and ICT adoption among farmers

Household size (X_5): Household size is negative (-0.0538) with marginally significant (10%) effect. Larger households are slightly less likely to use ICT and social media for agricultural purposes. This could be because larger families might have less time or resources to invest in technology, or they may rely on traditional methods of accessing agricultural information. The negative effect of household size on ICT use is consistent with Adebayo (2017), who noted that larger households face greater financial constraints, limiting their ability to invest in technology.

Stock size (X_7): Stock size has a positive (8.6964) effect on ICT and social media use, and is statistically significant at 5%. This suggests that farmers with larger stocks are much more likely to use ICT and social media, likely because large-scale operations demand more advanced tools for accessing agricultural information to manage the farms efficiently. The strong positive correlation between stock size and ICT use mirrors findings by Falola *et al*. (2021)**,** who found that larger-scale operations require more advanced tools for efficient farm management, making ICT use more prevalent among these farmers.

Annual income (X_8): Annual income has a positive coefficient (1.20860) and is significant at 5%. Higher annual income is positively and significantly associated with the likelihood of using ICT and social media. This result supports the idea that wealthier individuals have better access to the necessary resources (such as smartphones, computers, and internet access) to engage with ICT and social media platforms. The positive effect of annual income on ICT adoption supports Olaniyi (2013)**,** who reported that wealthier farmers are more capable of investing in ICT tools, such as smartphones and internet access, enhancing their ability to engage with social media for agricultural purposes. This relationship was also highlighted by Baye (2016)**,** who found that income levels play a significant role in ICT accessibility.

Table 3: Factors Influencing Use of ICT and Social Media Platform for accessing Agricultural Information

Variable	**Coefficient**	**Std Error**	**Z**	**P value**
Constant	16.8951	6.6256	2.55	0.011
Age	-1.2068	.4904	-2.46**	0.014
Gender (X_2)	-.3138	.2302	-1.36	0.173
Marital status (X_3)	.4421	.4351	1.02	0.310
Educational status (X_4)	.0958	.0562	1.70*	0.088
Household size (X_5)	-.0538	.02831	-1.90*	0.057
Farming experience (X_6)	2.5581	1.6822	1.52	0.128
Stock size (X_7)	8.6964	3.4680	2.51**	0.012
Annual income (X_8)	1.2086	.5732	2.11**	0.035
No. of observations	= 136			
LR Chi2 (7)	= 30.17			
Log likelihood	= -76.0870			
Pseudo R^2	= 0.1654.			

Note: ***, ** and * Significant at 1%, 5% and 10%

Constraints to Use of ICT and Social Media Platforms among Farmers

The results in Table 4 highlight the key challenges farmers face in using ICT and social media platforms to access agricultural information. These constraints are ranked based on their frequency of occurrence, reflecting the most pressing issues as identified by the respondents.

1. Inadequate Extension Support (66.0%, Ranked 1st): The most commonly reported constraint is the lack of adequate extension support. Farmers often depend on agricultural extension officers to guide them in accessing and using ICT tools and social media platforms. When this support is insufficient, farmers struggle to adopt new technologies. This underscores the crucial role of extension services in facilitating the effective use of ICT, showing that integrating digital tools with traditional extension methods can significantly enhance farmers' access to agricultural information.

2. Poor Electricity and Internet Connectivity (64.0%, Ranked 2nd): The second-highest constraint is the unreliable or non-existent infrastructure in rural areas, particularly concerning electricity and internet access. Farmers in these regions face difficulties in charging their devices and maintaining consistent online connectivity. This lack of infrastructure severely limits their ability to use ICT tools, emphasizing the urgent need for better rural infrastructure to support technological adoption.

3. Limited Awareness of Available Platforms (56.0%, Ranked 3rd): Over half of the farmers reported that they are not aware of the various ICT platforms and social media tools available to access agricultural information. This lack of awareness prevents them from taking advantage of useful technologies. The findings suggest that more comprehensive outreach and education programs are needed to ensure that farmers are informed about the platforms they can use and the benefits these tools offer.

4. Language and Literacy Barriers (54.0%, Ranked 4th): Language and literacy challenges are another significant constraint, affecting over half of the respondents. Many farmers, particularly in rural areas, may struggle to understand the content on ICT platforms due to language differences or low literacy levels. This highlights the need for digital tools to offer local language options and user-friendly interfaces that cater to farmers with varying literacy levels, making the information more accessible.

5. High Cost of Technology (43.0%, Ranked 5th): The high cost of purchasing and maintaining technology, such as smartphones, computers, and internet services, remains a barrier for many farmers. While there are more affordable options available today, the costs are still prohibitive for many small-scale farmers. This finding suggests that providing financial support or subsidies for technology could increase the adoption of ICT tools among farmers with limited resources.

6. Low Digital Literacy (42.0%, Ranked 6th): A significant number of farmers cited low digital literacy as a challenge. Even when they have access to technology, many farmers lack the skills needed to effectively use ICT platforms and social media for agricultural purposes. This indicates the need for targeted digital literacy training programs, particularly for older or less-educated farmers, to help them become more comfortable with technology.

7. Economic Constraints (34.4%, Ranked 7th): Although ranked lower, economic constraints still present a barrier. Farmers with limited financial resources may prioritize immediate needs like food and household essentials, leaving little room for investing in technology or internet services. This underscores the importance of improving the overall economic conditions of rural farmers, as better financial stability could encourage more investment in ICT tools.

Table 3: Constraints to Use of ICT and Social media by Farmers

Constraints	*Frequency	Percentage	Rank
Lack of electricity and internet connectivity	115	64.0	2nd
High cost of technology	78	43.0	5th
Low digital literacy	76	42.0	6th
Limited awareness of available platforms	101	56.0	3rd
Limited extension support	119	66.0	1st
Language and literacy levels	97	54.0	4th
Economic constraint	62	34.4	7th

***Multiple responses**

Conclusions

The study concludes that ICT and social media have the potential to significantly enhance the access of poultry farmers to agricultural information, thereby improving productivity and sustainability. However, several challenges limit the adoption of these technologies. Farmers with higher education, younger age, and higher income are more likely to use ICT and social media for farming activities, while older, less educated, and lower-income farmers are less likely to adopt these tools. Addressing the identified constraints—such as inadequate extension support, poor internet connectivity, and high costs—will be crucial for maximizing the benefits of ICT and social media in poultry farming. The study calls for targeted interventions to promote the use of digital tools, particularly among underserved farmers.

Recommendations

Based on the findings of this study, the following recommendations were made:

1.Strengthen Extension Services: There is a need for the government and agricultural institutions to enhance extension services by integrating digital tools into their outreach programs. This will help farmers receive timely information and support.

2.Improve Infrastructure: The government should invest in rural infrastructure, including reliable electricity and internet connectivity, to support the use of ICT in agriculture. Better connectivity will enable farmers to access information more effectively.

3.Promote Digital Literacy: Training programs should be organized to improve farmers' digital literacy, particularly for older or less-educated farmers. This will ensure that they can effectively use ICT tools for farming activities.

4.Subsidize Technology Costs: Policymakers should consider providing financial support or subsidies for purchasing ICT devices, such as mobile phones, and for covering internet costs. This would make technology more accessible to low-income farmers.

5.Encourage Private Sector Engagement: Telecommunications companies and ICT firms should be encouraged to offer affordable and tailored services to farmers, ensuring that even small-scale farmers can afford to use these technologies.

References

Adebayo, S. (2017). Enhancing Agricultural Productivity through Mobile-based Extension Services in Rural Nigeria. *Journal of Rural Development and Extension*, 11(2), 55-67.

Adepetun A. (2012). Accelerating broad band penetration through USPF Support. The Guardian Newspaper 1st August. Compulife pp. 25

Aker, J. C., & Mbiti, I. M. (2011). Mobile Phones and Economic Development in Africa. *Journal of Economic Perspectives*, 24(3), 207-232.

Arokoyo, T. (2005). ICTs Application in Agricultural Extension Service Delivery. *Agricultural Extension in Nigeria*, 145-157.

Balkrishna, B. B. and Deshmukh, A. A, (2017). A study on role of social media in agriculture marketing and its scope. *Global Journal of Management and Business Research: E Marketing.* Vol 17 (1), 33-36.

Baye, E. (2016). The Role of Social Media in Agricultural Marketing: A case study of poultry farmers. *Journal of Agricultural Science and Technology*, 12(3), 45-60.

Falola, A., Mukaila, R., & Kudabo, A. M. (2021). Economic Effect of Social Media on Small-scale Poultry Farmers, evidence from Nigeria. *International Journal of Agricultural Science, Research and Technology in Extension and Education Systems*, 11(3), 163-172.

Italie, H., (2015). Report: Social media drives news consumption. Retrieved on 27/03/2017 from http://www.csmonitor.com/Technology/2015/0430/ Report-social-media-drives-news-consumption. Published on May 30, 2015.

Michael, N and Jeffrey, D. J. (2014). The Role of Importance Perceptions in Participant Sport. *Journal of Physical Education and Sports Management.* Vol.1 (2), 29-52.

Ministry of Agriculture (MOA), (2013). State of Indian Agriculture 2012-13. Published by the Ministry of Agriculture, Department of Agriculture and Co-operation, Directorate of Economics and Statistics, New Delhi.

Msoffe, P. L., Bunn, D., Muhairwa, A. P., Mtambo, M. M. A., Mwamhehe, H., Msago, A., & Mlozi, M. (2010). Farmers' Use of Mobile Phones for Accessing Agricultural Information in Tanzania. *International Journal of Agricultural Informatics*, 7(1), 100-110.

Ogbonna, O.I.; Agwu, A.E. (2013). Access and use of Information communication Technologies by Rural Farmers in Enugu North Senatorial Zone, Enugu State. *Journal of Agricultural Science* 3 (7): 264-270

Olaniyi, O. A. (2013). Assessment on Utilization of Information and Communication Technologies (ICTs) among Poultry Farmers in Nigeria: An emerging challenge. *Transnational Journal of Science and Technology*, 3(6), 29-43.

Omotayo, A. M. (2005). ICT and Agricultural Extension: Issues, prospects, and opportunities. *The Journal of Agricultural and Food Information*, 6(3), 123-135.

Ozor, N. and Madukwe, M. C. (2009). Role of information communication technology in agricultural development. In Echezona, B. C. (ed.). *General Agriculture: Principles and Practices*, Faculty of Agriculture, University of Nigeria, Nsukka. Pp. 20-24

Samansiri, M., & Wanigasundera, W. (2014). In-service Training and Awareness of ICT Tools among Extension Workers in Sri Lanka. *Journal of Extension Systems*, 30(2), 63-72.

Sokoya, A. A; Adefunke, O. A and Fagbola, B.O. (2014). Farmers Information Literacy and Awareness towards Agricultural produce and Food security: FADAMA111 programme in Osun State, Nigeria. African Journal of Agricultural Research vol. 4(12)

Suchiradipta, B., and Saravanan, R., (2016). Social media: Shaping the future of agricultural extension and advisory services, GFRAS interest group on ICT4RAS discussion paper, GFRAS: Lindau, Switzerland.

Tweeten, J. F. (2014). Communication Tools in Modern Agricultural Practices: Insights from Iowa cattle producers. *Agricultural Communications Journal*, 9(4), 110-120.

Climate Change and Agricultural Sustainability in Nigeria: Challenges and Policy Pathways, A Case Study of Kishi, Oyo State.

Yusuff Adebonuola Lawal[1], Oluwadare Adebisi[2]

[1]Mechanical and Mechatronics Engineering, Faculty of Engineering and Technology, Abiola Ajimobi Technical University, Ibadan, Nigeria. Email: yusuff.lawal@tech-u.edu.ng.

[2]Electrical and Electronics Engineering, College of Agriculture, Engineering and Sciences (COAES), Bowen University, Osun State, Nigeria.

Abstract

Climate change presents an increasingly negative impact on the agricultural sector as it threatens food security, the stability of the economy, and cultural systems. The Nigerian economy relies on agriculture, but climate changes affect all farming sectors, including subsistence and commercial agriculture. This paper examines how climate change affects agricultural sustainability in Kishi, a major farming community in Irepo Local Government Area of Oyo State. This study merges weather data from community surveys and interviews with key stakeholders to analyze the current relationship between climate change and farming outcomes. The research shows that Kishi farmers face unpredictable annual rainfall patterns, prolonged dry spells, higher temperatures, and new pest infestations that disrupt traditional agricultural practices, leading to reduced crop yields. Local farmers combine traditional farming methods with adaptive technologies while encountering several barriers to progress. To support climate-smart agriculture, we recommend sustained investment, the establishment of community-based adaptation programs, and improved access to climate information. This study will enhance resilience while maintaining agricultural sustainability in communities confronting rapid weather-related climate change.

Keywords: *Climate change, agricultural sustainability, adaptation strategies, smallholder farmers, climate resilience*

Introduction

Climate change represents a relatively direct threat to global food security and has broad effects on agricultural systems, especially in sub-Saharan Africa. In Nigeria, Agriculture is the backbone of the economy, which accounts for approximately 24% of the national gross domestic product (GDP) and employs approximately 36% of the working population, mostly in the rural areas (FAO, 2013). Nevertheless, increased temperatures, erratic ripple levels, and extreme weather trends (drought and flooding) are threatening agricultural output and the way of life of the farmer. These challenges are particularly acute in zones such as Oyo state, where smallholder farmers rely mostly on rain-fed farming in producing staple crops like cassava, maize, yam, etc. Within Oyo State, Kishi, which is in Irepo Local Government Area (LGA), is a crucial case study because of Kishi's location in the forest belt zone, where there is a seasonal shortage of water and a rising rate of flood incidents. The paper explores the meeting point between climate change and agricultural sustainability in Kishi, responding to the desperate need for sustainable farming systems to ensure food security, promote Nigerian stands to Sustainable Development Goals achievement, and particularly SDGs 2 (Zero Hunger) and 13 (Climate Action).

In Kishi, negative impacts of climate change include reduced rainy seasons, erratic planting cycles, and an escalated level of pests and diseases, thus depriving the farmers of income. Given the fact that smallholder farmers constitute the majority of Kishi's agricultural workforce, the challenges to their adopting climate-smart agricultural practices include, among others, lack of access to finance and technology, as well as extension services. In addition, institutional gaps such as inadequate funding to agriculture (Nigeria spends less than 5% of its national budget on the sector, while the Maputo declaration target is 10%) and weak enforcement of climate policies increase these weaknesses. Unaddressed, the sustainability of agriculture in Kishi (and other communities in Nigeria) continues to be at risk, with downstream effects on food security and rural development.

The selection of Kishi, Irepo LGA, was based on its dependence on rain-fed agriculture and its proximity to the scourge of climatic challenges that have larger implications for the rural Nigerian community. This part of the region's agro-ecological profile, characterized by a forest belt zone in which alternating water scarcity and flooding is a phenomenon, makes it a good place to embark on an investigation of climate adaptation strategies. In addition, Kishi's smallholder farmers implement a hybrid of traditional and emerging approaches, providing information on the viability and scalability of adaptation approaches. By concentrating on Kishi, this study is part of the larger debate on climate-resilient agriculture in Nigeria and sub-Saharan Africa, delivering practical recommendations for policymakers, researchers, and local stakeholders. This study aims to investigate the impact of climate change on agricultural sustainability in Kishi, Oyo State, and to propose policy pathways that enhance resilience among smallholder farmers.

1. What is the awareness and perception of climate change among the farmers in Kishi, Irepo Local Government Area?

2. What is the effect of climate change on agricultural production and sustainability in the area of the study?

3. How have farmers been adopting strategies to adapt to climate change?

4. What are the main socio-economic, infrastructural, and environmental problems of farmers in an attempt to adapt to climate change?

5. What policy interventions do we require to enhance agricultural sustainability and resilience to climate change in the local context?

The broad objectives of this paper are to research the effects of climate change on agricultural sustainability in Kishi, the Irepo Local Government Area, Oyo State, and to map effective policy routes to increase resilience and sustainability. To achieve this, the study aims to measure the perception and awareness of climate change among farmers in Kishi; investigate the impact of climate variation on crop production and food security in the study region; determine the adaptation practices of local farmers to climate change; measure the role of institutional support in enhancing climate resilience; explore the socioeconomic and infrastructural challenges that hinder human resources for sustainable agricultural production in the era of climate change; and make context-specific (local) policy recommendations that would drive climate-resilient agricultural practices.

Literature Review

Climate change is a stern challenge to the world of agriculture, which is being felt through erratic rains, increased temperatures, and the extraordinary weather conditions of droughts and floods (Imran *et al.,* 2022). Such changes lead to diminished crop production, increased prevalence of pests and diseases, and increased soil degradation, especially in tropical areas where they rely on rain-fed agriculture (Singh *et al.,* 2011). In sub-Saharan Africa, agriculture maintains 60% of livelihoods, climate variability accentuates food insecurity and economic vulnerability, and decimates smallholder farmers, some of whom have reduced adaptive capacity (Asuamah, 2017; Mwasha *et al.,* 2021; Bedeke, 2023).

In Nigeria, agriculture contributes roughly 24% to GDP and provides livelihoods for about 36% of the country's working population, making it very vulnerable to climate impacts (Adeosun *et al.,* 2021). According to research, climate variability has caused yield losses of up to 20% of staple crops such as maize, cassava, and yam because of the shorter rainy seasons, prolonged dry seasons, and flooding (David, 2024). A higher incidence of pests, such as fall armyworm and soil erosion, aggravates productivity losses, especially in Nigeria's forest belt zones (Adunola *et al.,* 2021; Anjorin *et al.,* 2022). In Oyo State, where agriculture is the most common occupation, smallholder farmers need more targeted adaptation because limited access to climate-smart technologies, credit, and extension services presents them with additional challenges (Alo, 2020).

This study uses three theoretical frameworks to examine the impacts of climate change and adaptation strategies in Kishi. The Sustainable Livelihoods Framework (SLF) is a systematic method for evaluating farmers' assets in human, social, financial, physical, and natural capacities and vulnerabilities to climate shocks, with some indication of adaptive capacity (Das & Ansari, 2021; Guo *et al.,* 2022; Wang *et al.,* 2024). Risk and Vulnerability Theory explores how climate stressors combine with socioeconomic aspects of the affected population, such as income and education, to shape the resilience of the population, which in turn expounds the differences in farmers' abilities to adapt to climate risks in Kishi (Thomas *et al.,* 2019). The Resilience Check Toolkit (Srivastav *et al.,* 2021; Roohi *et al.,* 2025; Baraj *et al.,* 2024) measures the robustness, adaptability, and sustainability of adaptation measures, such as water harvesting or crop diversification, to deliver long-term agricultural resilience. The collective set of each of these frameworks creates the opportunity for a wide range of analyses of Kishi's farming systems and policy recommendations.

Studies in Oyo State have recorded the vulnerability of rain-fed agriculture to climate change, with erratic rainfall and increased temperatures decreasing the yields of some of the most important crops such as cassava and maize (Adekunle, 2023). Some of the proposed climate-smart agricultural practices (CSAP), such as agroforestry, intercropping, and water harvesting, have been suggested to increase resilience. However, adoption rates are slow because of funding, a lack of extension services, and a lack of awareness (Fawole & Aderinoye, 2021).

Adetayo (2022) conducted a particular study in Kishi, Irepo LGA, Oyo State, on the adoption of climate change adaptation strategies, underlining technologies such as micro check dams, rainwater harvesting to deal with a water deficit, and unsatisfactory soil-water management. Age, education, plot size, and farmers' access to extension services were found to be the main factors determining adoption, whereby farmers had a higher uptake of adaptive practices (Oke *et al.,* 2025). Nonetheless, various frustrations such as a lack of credit facilities and poor technical backup, coupled with low awareness, have demoralized wider use, necessitating focused interventions in the Oyo State (Adetayo, 2022). On the national level, studies have revealed institutional hindrances such as underfunding of agriculture by the Nigerian state (less than 5% of the total national budget in comparison to the target of 10% by the Maputo declaration) and poor enactment of policies like the National Adaptation Strategy and Plan of Action on climate change (Okon & Christopher, 2018)

Despite these contributions, several gaps remain in the literature. First, longitudinal studies on the long-term effectiveness and sustainability of adaptation strategies at Kishi are lacking, resulting in a lack of evidence for viable and scalable solutions. Second, there is limited research on the role of gender and youth in adaptive processes, even though they play a considerable role in Kishi's agricultural systems. Third, despite valuable regional studies in Oyo State, they often fail to consider Kishi's unique agroecological problems, such as the perpetual cycle of water scarcity and torrents of floods in the forest belt zone. Finally, there is a lack of analysis regarding how national climate policies translate to the grassroots level in Kishi, particularly concerning access to climate information services and institutional support. This study addresses these gaps by presenting a case study of Kishi, which contributes to the development of context-specific policy pathways for climate-resilient agriculture in Nigeria.

Research Design

This study employs a mixed-methods approach to case studies to examine the impacts of climate change on smallholder agriculture and the uptake of climate-smart agricultural practices (CSAP) in Kishi, Irepo Local Government Area (LGA), Oyo State, Nigeria. This combined approach integrates quantitative data with qualitative inputs to provide a comprehensive understanding of vulnerabilities related to climate change and adaptation measures. The case study focuses on Kishi because of its unique agroecological conditions, where the forest belt consistently faces water scarcity along with flooding, and there are few studies on its specialized agricultural systems.

Study Area

Kishi is situated in Irepo LGA, Oyo State, within Nigeria's forest belt zone, featuring a tropical climate defined by a rainy season and dry season (April-October and November-March). This area experiences unpredictable rainfall, rising temperatures, and flooding during the rainy months, which affect rain-fed crops such as cassava, maize, and yam. Smallholder farmers, who make up over 70% of Kishi's agricultural workforce, rely on traditional farming practices, with minimal use of climate-smart technologies. The choice of Kishi is justified by its vulnerability to climate change, which has been insufficiently represented in regional studies, as well as its relevance to national climate adaptation policies, such as the National Adaptation Strategy and Plan of Action on Climate Change (NASPA–CCN).

Sampling and Data Collection

Sampling

The study focuses on smallholder farmers in Kishi, who farm less than five hectares of land. A multi-staged sampling method was used. First, purposive sampling was conducted on Six farming communities in Kishi, based on their exposure to climate risks (e.g., flooding and drought) and their level of agricultural activity. Second, a random sampling of 600 farmers (100 per community) was carried out to ensure that there was a representation of gender (at least 40% women) and age (including youth aged 18–35 years) to fill the literature gaps in these groups. In addition, ten key informants, comprising extension officers, community leaders, and local policymakers, were purposively selected based on their knowledge of agriculture and local-level adaptation to climate change.

Data Collection Methods

1. Structured Surveys: A questionnaire was administered to 600 farmers who filled in a questionnaire in which they provided information on demographics (age, gender), farming practices (years of farming, type), climate change observations (such as drought or flooding), effects on crops/livestock (crop failure, water shortage), coping strategies (such as irrigation and resistance). The survey had multiple-choice and select-all-that-apply questions adapted from Oyewole *et al.* (2024). Focus Group Discussions (FGDs): Six FGDs (one for each community, except one due to logistical reasons) were scheduled, with 8 – 10 farmers each divided into categories of males and females to examine the barriers to adaptation and gender roles.

3.Key Informant Interviews (KIIs): Semi-structured interviews were conducted with 10 key informants to examine the institutional support and implementation of the NASPA-CCN.

Data Analysis

Survey data were analyzed using descriptive statistics to summarize climate impact and coping strategies. Correlation analyses of various forms were used to determine the relationship between climate change and crop/livestock effects, and logistic regression was pre-planned to determine the determinants of coping strategies (e.g., gender and access to support). SPSS version 26 was used for quantitative analysis, resulting in bar charts, heatmaps, and boxplot representations of distributions and outliers. Having collected qualitative data from FGDs and KIIs, it will be thematically analyzed using NVivo 12, following Braun and Clarke (2006). In future analyses, the Resilience Check Toolkit will determine the sustainability of CSAP (Ifejika-Speranza, 2010).

Informed consent was obtained, surveys and interviews were conducted in Yoruba and English, depending on the preferences of the participants. Individuality was achieved by using unique identifiers. There was cultural sensitivity in consultations with community leaders.

Results and Discussions

This section explains and discusses the results of a climate change survey conducted in Kishi, Irepo Local Government Area, Oyo State, which included 600 interviewees. The aim is to determine people's knowledge, opinions, and worries about climate change and how much they are adapting to support agricultural sustainability.

Demographic Characteristics of Respondents

The research population consisted of 253 females (42.2%) and 347 males (57.8%), highlighting the involvement of women in agriculture. A significant portion of the respondents (45.2%) were between 15 and 35 years old, with an average age of 38. This indicates that a large proportion of farmers are actively working, including both young and more experienced farmers. Evidence suggests that climate-smart technology has potential among youth, although most of the older group tends to stick to their traditional practices. Figure 1 displays charts of the Gender Distribution of Respondents, while Figure 2 presents charts of the Age Distribution of Respondents.

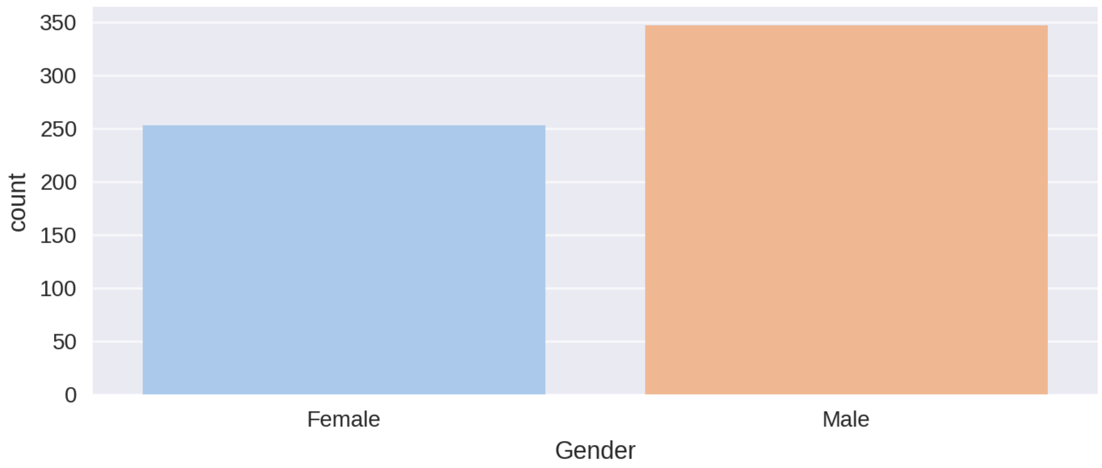


Figure 1: Gender Distribution of Respondents

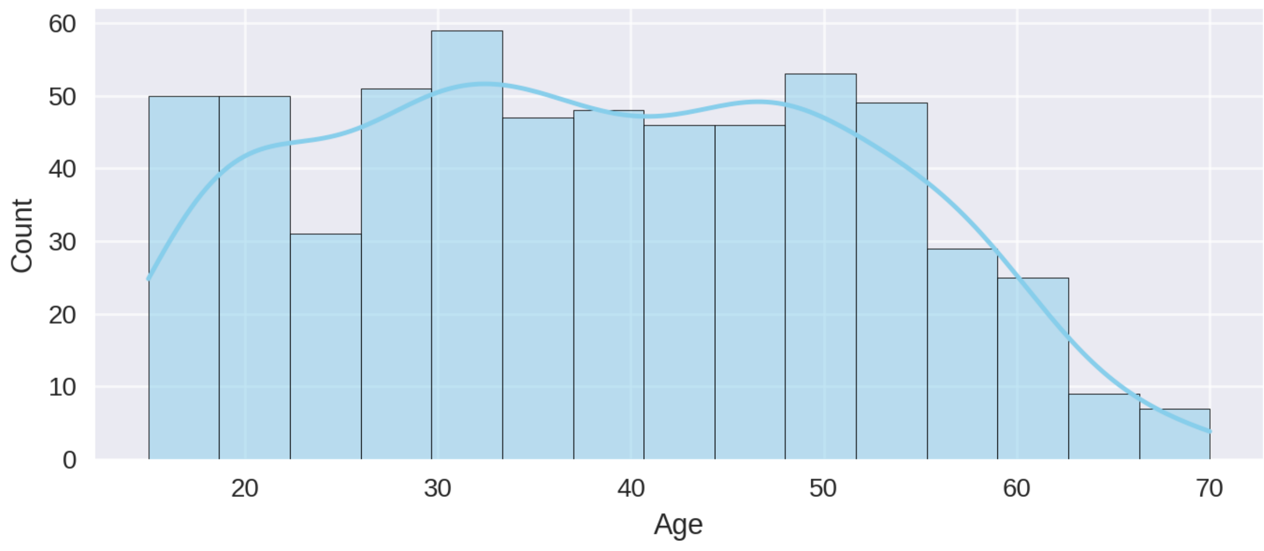


Figure 2: Age Distribution of Respondents

Awareness of Climate Change

According to the survey, 253 respondents were aware that climate change is happening, while 227 said they did not know. A large number of farmers do not formally learn about climate-related problems, despite being directly exposed to them. A lack of awareness might stop farmers from adopting effective ways to respond to climate change and might mean extension services are lacking or people do not get the information they need, according to Adetayo (2022). Figure 3 shows charts of the Respondents' Awareness of Climate Change

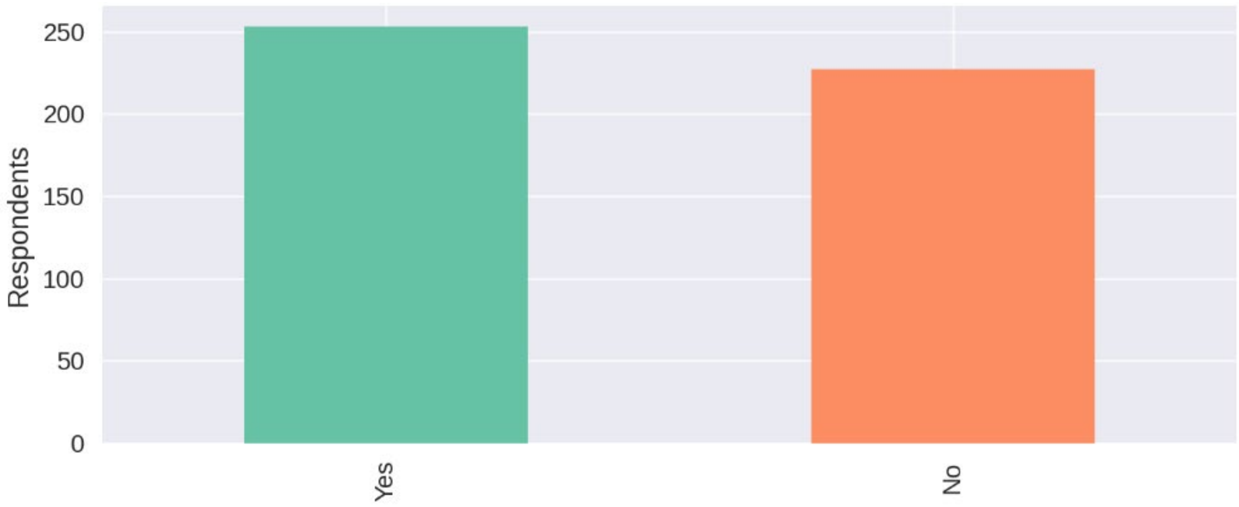


Figure 3: Respondents' Awareness of Climate Change.

Perception of Climate Change Effects on Agriculture

Responses to whether climate change impacts agriculture varied widely: 93 individuals agreed, 90 strongly agreed, 113 disagreed, 92 strongly disagreed, and 92 individuals had no strong opinion. Differences in the levels of knowledge among respondents may come from differences in their education, background on the farm, or access to specialist information. It agrees with Das & Ansari (2021), who said that perception can depend on how much information and support people receive.

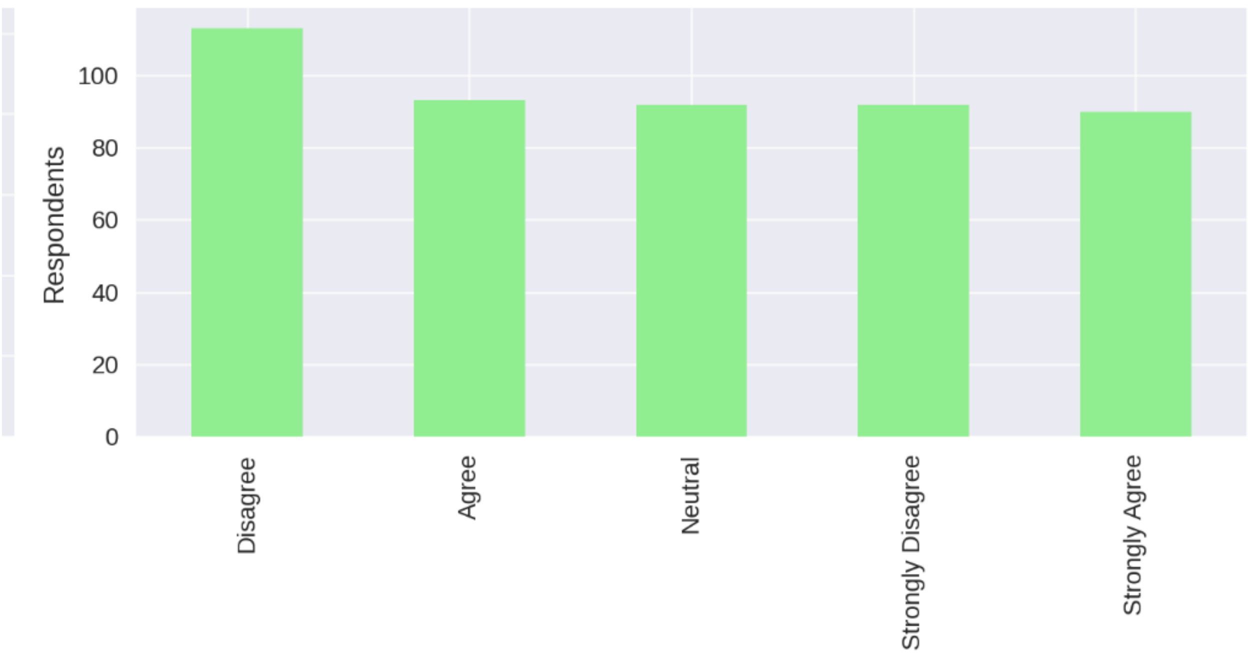


Figure 4: Perceptions of Climate Change Impact on Agriculture

Level of Awareness

According to our results, about 28% of adults were very aware, 25% had average knowledge and another 26.7% were unaware of the risks. Realizing that many people feel they understand climate change more than they truly do, it is clear that programs should be recreated so they are easy for each group to connect with. Figure 5 shows charts of the Level of Awareness about Climate Change.

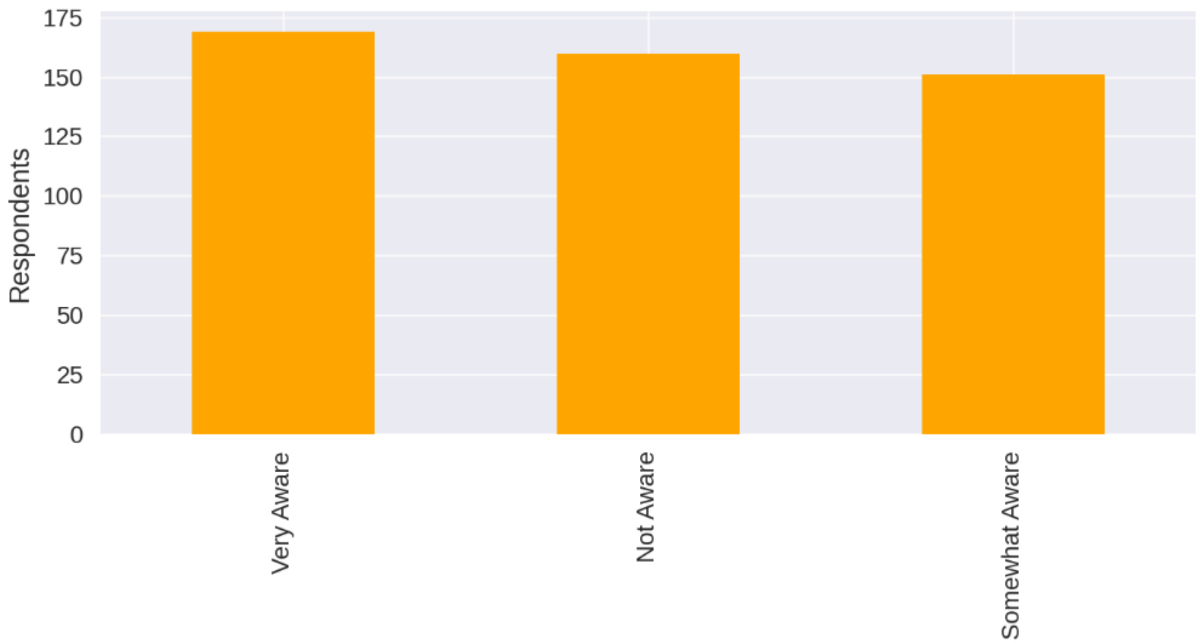
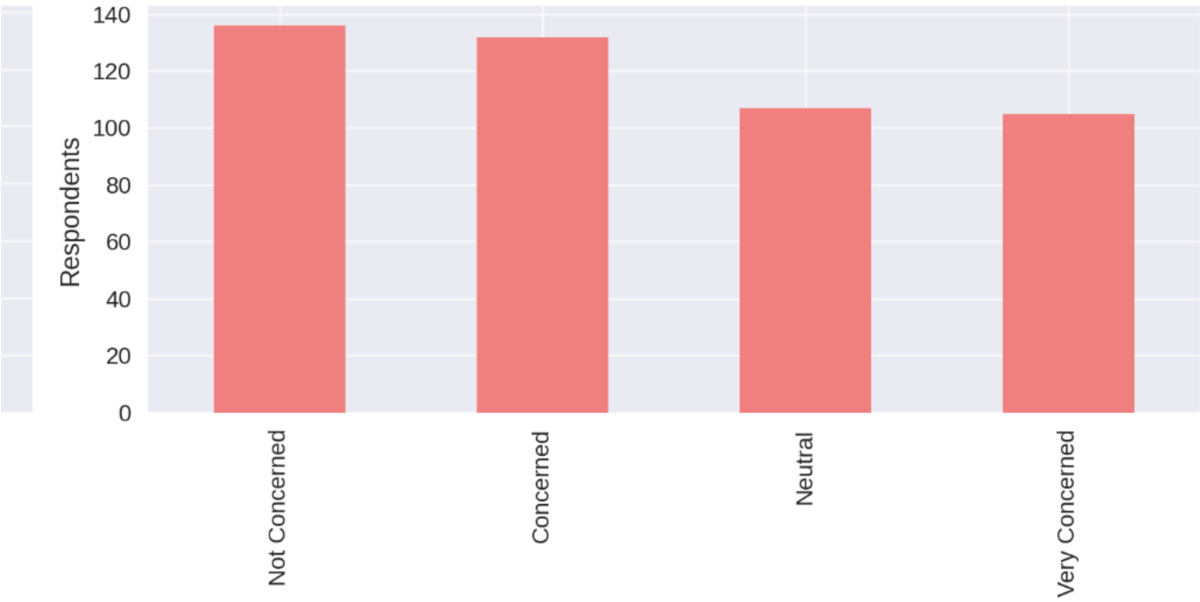


Figure 5: Level of Awareness about Climate Change

Concern about Climate Change

There was not much agreement among participants when I asked about their level of concern. A majority of 136 participants answered that they were not concerned, while 130 answered that they were concerned, and 105 stated that they were highly concerned. It shows that some farmers fully recognize the dangers of climate change, but others might not agree. It could be because farmers are prioritizing their income and don't see a direct link between their present farming issues and risks that may appear later. Figure 6 shows the charts of the Concern Levels about Climate Change.

Figure



5: Concern Levels about Climate Change

Through the Sustainable Livelihood Framework, we found that climate change has reduced farmers' financial and natural resources, and their lack of extension services has reduced their human and social capital. Based on the Risk and Vulnerability model, lack of adaptation ability and high exposure and sensitivity put farmers at even greater risk from climate shocks. Overall, the Resilience Toolkit demonstrates that, while a few strategies are starting to develop, the community is not prepared for major changes. Local organizations must be encouraged, and better warnings and strong, resilient structures need to be designed with local concerns in mind.

Policy Recommendations

To increase sustainable farming in Kishi and similar regions because of climate change, new policies should be introduced. First, more farmers should be supported using climate-smart techniques in agriculture (CSA). The government and its partners should arrange local workshops on ways to use drought-resistant seeds, improve irrigation techniques, and methods to preserve and enrich the soil with mulch and compost. To ensure the set the practices continue, they should be included in ongoing agricultural programs.

Additionally, it is necessary to create community-based services that provide climate information. Farmers often do not have access to live weather updates that can guide planting activities. Local weather stations, radio alerts, and forecast SMS messages in local languages can greatly help farmers to be better prepared. Users from the local community should participate in designing these services to ensure that they meet their needs.

Thus, agricultural extension systems should be updated and improved. Based on the results, it seems that not many trained officers offer technical counsel and advice about climate change to farmers in Kishi. More extension agencies need to be employed and trained on CSA and digital resources so that they can help reach females and youngsters who usually do not receive proper support.

Enhancing the infrastructure in rural areas is important for future adjustments. With proper irrigation, water collection, and better roads, farmers can resist the impact of bad weather and handle their harvest safely. Focusing on solar-powered boreholes can help farmers produce crops during both the wet and dry seasons.

Additionally, more steps must be taken to make affordable credit and risk-sharing mechanisms available. It is important to motivate financial institutions to create credit schemes to aid farmers and develop climate-related insurance. It would help align these loans with both cooperatives and farmer associations to promote collaboration and prevent many issues. farmers defaulting.

It is also important for climate policy to include insights from the local people in their formal adaptation plans. In Kishi, there are farmers who have already found useful solutions through indigenous methods, and these methods could become the basis for local solutions if encouraged by relevant authorities. Adapting to climate change is easier for farmers when they work together and participate in building and using new techniques.

Conclusion

In this study, we investigated how climate change has impacted agricultural sustainability in Kishi, Irepo Local Government Area of Oyo State, Nigeria, by focusing on understanding farmers' awareness, identifying climate-related challenges, noting current adaptation efforts, and suggesting policy solutions. According to the data, while farmers in Kishi recognize the effects of climate change, such as unusual rainfall patterns, prolonged droughts, increased pest issues, and decreased crop yields, they struggle to cope with these challenges. Currently, coping strategies are primarily reactive, relying on poorly constructed irrigation systems, limited institutional support, and delayed or inadequate climate information.

This indicates that smallholder farmers in Kishi are vulnerable to environmental risks, while also lacking adaptive measures and facing largely overlooked needs. Each research objective is based on evidence showing that without appropriate policy support for rural infrastructure, climate information, and access to financing, agriculture in the region may remain weak and highly threatened.

At the same time, this study has its limitations. Out of the 600 participants, all were drawn from one local government area and provided their responses, which could be influenced by memory and local perceptions. Additionally, although information from interviews and focus groups was valuable, triangulating the results by including remote sensing data or long-term yield data would have strengthened the conclusions.

Despite these limitations, the research offers insightful findings regarding the connection between agriculture and climate in rural Nigeria, which could be applied elsewhere. Recommendations such as promoting climate-smart agriculture, enhancing extension services, and developing local climate information systems can guide governments in similar regions toward better climate policies. To achieve long-term agricultural sustainability in Nigeria, it is essential that we adapt, foster inclusive communities, and secure necessary policies.

Acknowledgements

Completing this research was only possible with the assistance of several individuals and organizations. I am very grateful to the farmers and community members in Kishi, Irepo Local Government Area, who helped and gave freely of their time during our data collection process.

I would like to thank the local leaders and agricultural extension officers who helped me meet with the farmers and taught me about their agricultural challenges. I would also like to thank the Department of Mechanical Engineering at Abiola Ajimobi Technical University, Ibadan, Oyo State, as it enabled this research in an effective academic setting.

I am most grateful to God for giving me the strength and knowledge to finish this research.

References

Adekunle A (2023). Perceived Effect of Climate Change on Production Practices Among Cassava Based Farmers in Oyo State, Nigeria (Master's thesis, Kwara State University (Nigeria)).

Adeosun, O. T., Asare-Nuamah, P., & Mabe, F. N. (2021). Vulnerability analysis of Nigeria's agricultural output growth and climate change. Management of Environmental Quality: An International Journal, 32(6), 1352-1366.

Adetayo, A. O. (2022). Assessment of adoption rate of climate change adaptation strategies in Kishi, Oyo State, Nigeria. International Journal of Environmental Monitoring and Analysis, 10(2), 26–31. https://doi.org/10.11648/j.ijema.20221002.11

Adunola, M. P., Fayeun, L. S., & Fadara, A. B. (2021). Impact of climate change on armyworm infestation on maize in Nigeria: A review. Plant Breed. Crop Sci, 13, 158-167.

Alo, A. (2020). Smallholder Farmers' Understanding Of, and Attitudes To, Climate Change, Variability and Climate Smart Farming: A Case Study of South West Nigeria (Doctoral dissertation, Coventry University).

Anjorin, F. B., Odeyemi, O. O., Akinbode, O. A., & Kareem, K. T. (2022). Fall armyworm (Spodoptera frugiperda) (JE Smith) (Lepidoptera: Noctuidae) infestation: maize yield depression and physiological basis of tolerance. Journal of Plant Protection Research, 12-21.

Asuamah Yeboah, S. (2024). Assessing Climate Change Impacts on Food Security in Africa: Regional Variations and Socio-Economic Perspectives.

Baraj, B., Mishra, M., Sudarsan, D., da Silva, R. M., & Santos, C. A. G. (2024). Climate change and resilience, adaptation, and sustainability of agriculture in India: A bibliometric review. Heliyon.

Bedeke, S. B. (2023). Climate change vulnerability and adaptation of crop producers in sub-Saharan Africa: a review on concepts, approaches and methods. Environment, development and sustainability, 25(2), 1017-1051.

Das, U., & Ansari, M. A. (2021). The nexus of climate change, sustainable agriculture and farm livelihood: contextualizing Climate Smart agriculture. Climate Research, 84, 23-40.

David, m. T. (2024). Assessing Climate Variability to the Vulnerability of Crop yield in Benue State Nigeria.

Fawole, B. E., & Aderinoye-Abdulwahab, S. A. (2021). Farmers' adoption of climate smart practices for increased productivity in Nigeria. In African handbook of climate change adaptation (pp. 495-508). Cham: Springer International Publishing.

Guo, A., Wei, Y., Zhong, F., & Wang, P. (2022). How do climate change perception and value cognition affect farmers' sustainable livelihood capacity? An analysis based on an improved DFID sustainable livelihood framework. Sustainable Production and Consumption, 33, 636-650.

Imran, Benkeblia, N., Amanullah, & Al-Tawaha, A. R. M. S. (2022). Climate Change and Agriculture: State of the Art, Challenges, and Perspectives. Climate Change and Agriculture: Perspectives, Sustainability and Resilience, 1-27.

Mwasha, S. I. (2021). Livelihoods, vulnerability, and adaptation to climate change of small-holder farmers in Kilimanjaro, Tanzania (Doctoral dissertation).

Oke, f. O. (2025). Livelihood activities and determinants of Adoption of Climate Change Adaptation Strategies among Farming Households in Oyo State, Nigeria. Scientific Papers Series Management, Economic Engineering in Agriculture & Rural Development, 25(1).

Okon, E. B., & Christopher, A. O. (2018). Agricultural expenditure, Maputo declaration target and agricultural output: A case study of Nigeria. International Journal of Economics, Commerce and Management, 4(7), 516-531.

Oyewo, I. O., Raufu, M. O., Oladosu, B. O., & Adelalu, K. O. (2018). Climate Change and Adaptation Strategies: Farmers Perception in Oyo State, Nigeria. Current Research in Agricultural Sciences, 5(2), 32-41.

Roohi, Kamboj, P., Soni, P. G., Rani, S., Sukirtee, Kumar, R., & Mishra, A. K. (2025). Advancing Climate-Resilient Agriculture: Adaptive Strategies and Soil-Centric Approaches for Mitigation. In Transition to Regenerative Agriculture: Principles and Indicators of Soil Health Management (pp. 55-75). Singapore: Springer Nature Singapore.

Singh, B. K., Delgado-Baquerizo, M., Egidi, E., Guirado, E., Leach, J. E., Liu, H., & Trivedi, P. (2023). Climate change impacts on plant pathogens, food security, and paths forward. Nature Reviews Microbiology, 21(10), 640-656.

Srivastav, A. L., Dhyani, R., Ranjan, M., Madhav, S., & Sillanpää, M. (2021). Climate-resilient strategies for sustainable management of water resources and agriculture. Environmental Science and Pollution Research, 28(31), 41576-41595.

Thomas, K., Hardy, R. D., Lazrus, H., Mendez, M., Orlove, B., Rivera-Collazo, I., ... & Winthrop, R. (2019). Explaining differential vulnerability to climate change: A social science review. Wiley Interdisciplinary Reviews: Climate Change, 10(2), e565.

Wang, J., Wang, H., & Wu, Z. (2024). Factors influencing farmers' adaptation willingness under landslide risks: Using an extended sustainable livelihood framework. International Journal of Disaster Risk Reduction, 107, 104512.

Kümes İklimlendirmesinde Sensör Ağları ve Yapay Zekâ Uygulamaları

Mustafa Ersoy[1], Koray Şengül[2], M. Enes Topal[2], Zeynel Cebeci[2]

[1,2] Çukurova Üniversitesi Ziraat Fakültesi Zootekni Bölümü, 01330 Adana, Türkiye
[1] m.ersoy188@gmail.com

Abstract

The aim of this study is to enhance animal welfare by optimizing poultry house climate control through the use of IoT and sensor networks. The system incorporates DHT11 temperature and humidity sensors, MQ-2 gas sensors, two DC fans, an L9110S motor driver, and a Wemos D1 (ESP8266) microcontroller. Data transmission is achieved via the MQTT protocol over Wi-Fi, and a user-friendly web interface has been developed using the Node-RED platform. In addition, data obtained from the sensors are transmitted to an artificial intelligence model through OpenRouter, enabling the system to be supported with AI-based insights. Consequently, not only instantaneous environmental parameters (temperature, humidity, and harmful gas concentrations) but also AI-driven analyses are taken into account, allowing for more precise and proactive climate management. This approach reduces animal stress levels, protects respiratory health, and sustainably supports optimal living conditions.

KeyWords: *IoT, Sensor Networks, ArtificialIntelligence, PoultryClimate Control, MQT,*

Özet

Bu çalışmanın amacı, IoT ve sensör ağları kullanarak kümes iklimlendirmesini optimize ederek hayvan refahını artırmaktır. Çalışmada DHT11 sıcaklık ve nem sensörleri, MQ-2 gaz sensörleri, iki adet DC fan, L9110S motor sürücüsü ve Wemos D1 (ESP8266) mikrodenetleyicisi kullanılmıştır. WiFi üzerinden MQTT protokolü ile veri aktarımı sağlanmış, Node-RED platformu ile kullanıcı dostu bir web arayüzü geliştirilmiştir. Ayrıca, sensörlerden elde edilen veriler OpenRouter aracılığıyla yapay zekâ modeline gönderilmekte, sistem bu verilerden çıkarılan yorumlarla desteklenmektedir. Böylece yalnızca anlık çevresel parametreler (sıcaklık, nem, zararlı gaz seviyeleri) değil, aynı zamanda yapay zekâ temelli analizler de dikkate alınarak daha hassas ve proaktif bir iklimlendirme sağlanmaktadır. Bu yaklaşım, hayvanların stres düzeyini azaltmakta, solunum sağlığını korumakta ve optimum yaşam koşullarını sürdürülebilir şekilde desteklemektedir.

Anahtar Kelimeler: *IoT, SensörAğları, Yapay Zeka, Kümesİklimlendirmesi, MQTT*

Giriş

Son yıllarda, tarım ve hayvancılık sektörlerinde teknolojik gelişmeler, üretim süreçlerini daha verimli ve sürdürülebilir hale getirmek amacıyla hızla benimsenmektedir. Özellikle Nesnelerin İnterneti (IoT: Internet of Things) teknolojisi, tarımsal üretimde veri toplama, analiz etme ve otomatik kontrol sistemlerini mümkün kılarak, üreticilere daha bilinçli kararlar alma imkânı sunmaktadır (Durgun, 2021). Bu teknolojilerin kanatlı hayvancılık sektöründe kullanımı hem üretim verimliliğini artırmakta hem de hayvan refahını iyileştirmektedir (Aydın, 2020).

Kanatlı hayvancılıkta, özellikle etlik piliç ve yumurtacı tavuk yetiştiriciliğinde, hayvanların yaşam kalitesini doğrudan etkileyen faktörlerin başında çevresel koşullar gelmektedir. Sıcaklık, nem, hava kalitesi ve ışık düzeyi gibi etmenler, hayvanların sağlığını ve üretkenliğini doğrudan etkilemektedir. Bu nedenle, kümes ortamının sürekli izlenmesi ve kontrol edilmesi, hayvan refahının sağlanması açısından büyük önem taşımaktadır (Aydın, 2020; Durgun, 2021).

IoT bu bağlamda devreye girerek, çevresel parametrelerin gerçek zamanlı olarak izlenmesini ve analiz edilmesini mümkün kılmaktadır. Örneğin, sıcaklık ve nem sensörleri aracılığıyla toplanan veriler, Wi-Fi modülleri sayesinde merkezi bir sunucuya iletilmekte ve burada işlenerek kümes ortamının durumu hakkında bilgi edinilmektedir (Durgun, 2021). Bu veriler, aynı zamanda görselleştirilerek, üreticilerin daha bilinçli kararlar almasına olanak tanımaktadır (Aydın, 2020).

Ancak, çevresel faktörlerin yanı sıra, hayvanların davranışsal ve fizyolojik durumlarını izlemek de hayvan refahının değerlendirilmesinde kritik bir rol oynamaktadır. Görüntü işleme ve ses analizi gibi teknolojiler, hayvanların davranışlarını analiz ederek, stres, hastalık veya diğer olumsuz durumların erken tespitini sağlamaktadır (Aydın, 2020). Bu tür teknolojik sistemler, hayvanların refahını artırmak için önemli araçlar sunmaktadır.

Türkiye'de, hayvan refahı konusunda yasal düzenlemeler Avrupa Birliği standartlarına uyumlu olarak geliştirilmektedir. Ancak, uygulamada karşılaşılan zorluklar ve eksiklikler, bu düzenlemelerin etkinliğini sınırlamaktadır Bu bağlamda, IoT tabanlı sistemlerin entegrasyonu hem üreticilerin daha verimli çalışmasına hem de hayvanların refahının artırılmasına katkı sağlamaktadır (Durgun, 2021).

Bu çalışmada, IoT tabanlı bir akıllı kümes iklimlendirme sistemi önerilmiştir. Sistem, çevresel sensörlerden aldığı verileri Arduino platformu aracılığıyla işler ve Wi-Fi modülü sayesinde MQTT protokolü üzerinden bir sunucuya iletir. Node-RED yazılımı, bu verileri analiz ederek mantıksal işlemler gerçekleştirir ve görselleştirme sağlar. Ayrıca, sistemin verileri MySQL veritabanına kaydederek, geçmiş verilerin analizine olanak tanır. Belirli saat aralıklarında, OpenRouter kullanılarak API üzerinden veriler gönderilir ve kullanıcıdan geri bildirim alınır. Bu geri bildirimler, fanların veya ısıtıcıların açılıp kapanması gibi öneriler sunarak, kümes ortamının optimum koşullarda tutulmasına yardımcı olur.

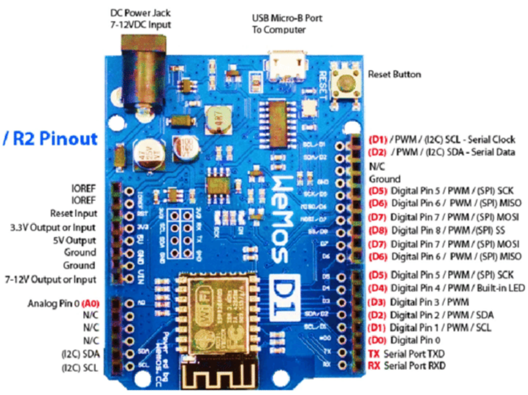
Sonuç olarak, bu tür akıllı sistemlerin entegrasyonu, kanatlı hayvancılık sektöründe hem üretim verimliliğini artırmakta hem de hayvan refahını iyileştirmektedir. Teknolojinin bu alandaki kullanımı sürdürülebilir ve etik üretim süreçlerinin önünü açmaktadır

Materyal ve Yöntem

Bu çalışmada, kanatlı hayvan kümeslerinde çevresel parametrelerin izlenmesi ve kontrolü yoluyla hayvan refahının artırılması amaçlanmıştır. Geliştirilen sistem, sıcaklık, nem ve hava kalitesi verilerini toplamakta, bu verilere göre fan ve ısıtıcıların otomatik olarak kontrol edilmesini sağlamaktadır.

Donanım Bileşenleri

Sistemin merkezinde ESP8266 tabanlı mikrodenetleyici kart kullanılmaktadır. Kart, Şekil 1'de görüldüğü gibi 32 bit ESP-8266EX işlemci ile 80/160 MHz hızında çalışmakta olup, 11 dijital giriş/çıkış pini, bir analog giriş ve mikro USB B tipi girişe sahiptir. Güç girişi 9–24V aralığında desteklenmektedir ve Arduino/NodeMCU IDE ile programlanabilmektedir. Flash bellek kapasitesi 4 MB olup, kompakt boyutları (68.6 mm × 53.4 mm) ve düşük ağırlığı (25 gr) ile IoT uygulamaları için uygundur.



Şekil 1. Wemos D1 mikrodenetleyicisi pin yapısı (Idris, M. R., et al.., 2021)

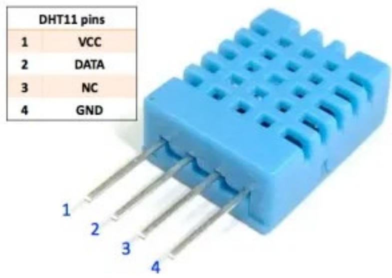
Tablo 1. NodeMCU'nun teknik özellikleri

Özellikler	Değer
MCU	ESP-8266EX
USB-Seri dönüştürücü	CH340

Çalışma gerilim	3.3V
Dijital G/Ç sayısı	11
Analog giriş sayısı	1 (maksimum 3.2V)
Saat hızı	80MHz/160MHz
Flash bellek	4MB
Boyutlar	68.6 mm x 53.4 mm (U x G)
Ağırlık	25gr

Sensörler

Sıcaklık ve Nem Sensörü: Kümes ortamındaki sıcaklık ve nem değerlerini ölçmek için Şekil 2'de görülen DHT11 kullanılmıştır. Sensör, 0°C ila 50°C aralığında ±2°C hassasiyetle sıcaklık ölçümü ve %20–90 RH aralığında ±5% bağıl nem hassasiyeti ile nem ölçümü gerçekleştirebilmektedir. DHT11, üzerinde mikrodenetleyici bulunan entegre bir modüldür ve kısa tepki süresine sahiptir. Dijital çıkışı sayesinde sensör, sıcaklık ve nem verilerini doğrudan mikrodenetleyiciye iletebilmektedir. Sensörün çalışma gerilimi 3.3–5V DC aralığında olup, maksimum akım tüketimi 2.5 mA'dır. Fiziksel boyutları yaklaşık 20 mm × 15 mm olup, montaj için iki adet 2 mm çapında delik içermektedir. DHT11'in bağlantısı 3-pin veya 4-pin seçenekleri ile sağlanabilir ve veri iletimi tek hatlı dijital bus üzerinden gerçekleşir. Bu yapı, sensörün ölçüm verilerini stabil ve güvenilir biçimde mikrodenetleyiciye aktarmasını mümkün kılmaktadır.



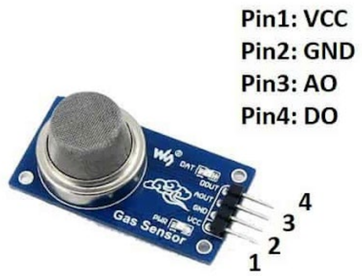
Şekil 2. DHT11 Sensörüne ait pin yapısı ve teknik özellikleri (Circuits4you.com, 2016)

MQ-2 Gaz Sensörü: Amonyak ve diğer zararlı gazların izlenmesinde görev almakta, kümes havasının kalitesini kontrol ederek fanların çalıştırılmasını sağlamak için Şekil 3'te görülen MQ-2 sensörü kullanılmaktadır. MQ-2, yanıcı ve patlayıcı gazları tespit etmek için kullanılan analog ve dijital çıkışlı bir gaz sensörüdür. Algılama aralığı 300–10.000 ppm arasında değişen propan, metan, LPG ve duman gibi gazları belirleyebilir. Sensör, iç yapısında yarı iletken metal oksit (SnO_2) tabanlı algılayıcı içerir ve gaz yoğunluğuna bağlı olarak direnç değişimi gösterir. Bu direnç değişimi, sensör üzerindeki yükselteç devresi sayesinde 0–5V arasında analog sinyale dönüştürülür.

Tablo 2. MQ-2 sensörünün temel teknik özellikleri

Özellikler	**Değer**
Algılanan Gazlar	LPG, Propan, Metan, Duman
Algılama Aralığı	300–10.000 ppm
Çıkış Tipi	Analog ve dijital
Çalışma Gerilimi	5V DC
Algılama Süresi	10sn
Fiziksel Boyut	32 mm x 20 mm x 18 mm

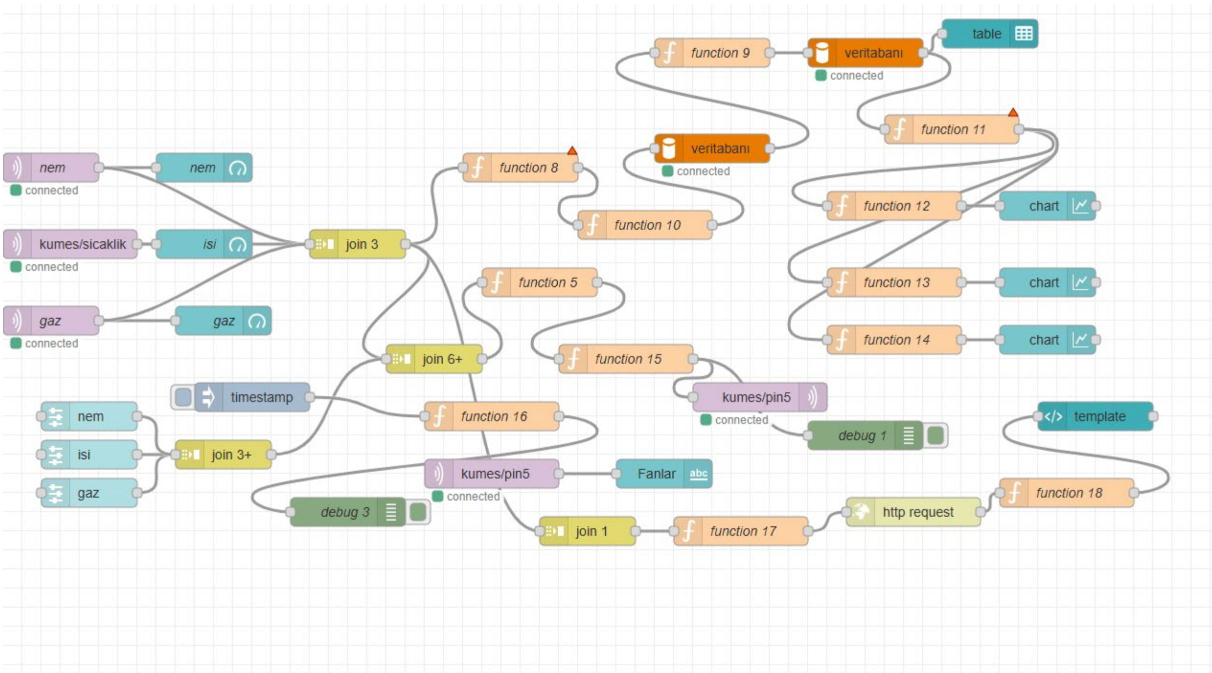
Sensör, analog çıkışı sayesinde mikrodenetleyici tarafından ölçülen gaz yoğunluğunu sürekli olarak izler. Sistemde bu veriler, kümes içi hava kalitesini değerlendirmek ve fanların otomatik olarak çalıştırılmasını sağlamak amacıyla kullanılmıştır. Sensör üzerindeki dijital çıkış ise, belirlenen eşik değeri aşılırsa anlık kontrol sinyali göndererek çalışmakta



Şekil 3. MQ-2 Sensörüne ait pin yapısı (Xeohacker, 2024)

Veri İletimi ve İşleme

Sensörlerden elde edilen veriler, ESP8266 mikrodenetleyicisinin Wi-Fi modülü aracılığıyla MQTT (OASIS, 2019) protokolü ile Home Assistant (Home Assistant, 2024) sunucusuna aktarılmaktadır. Home Assistant, Windows işletim sistemi üzerinde VirtualBox (Oracle, 2024) sanal makinesi içinde çalıştırılmıştır. Veriler, Node-RED (Node-RED, 2024) platformu üzerinden mantıksal işlemlerden geçirilmekte ve kullanıcıya localhost:1880/ui adresinde sunulan bir web arayüzü üzerinden görselleştirilmektedir.



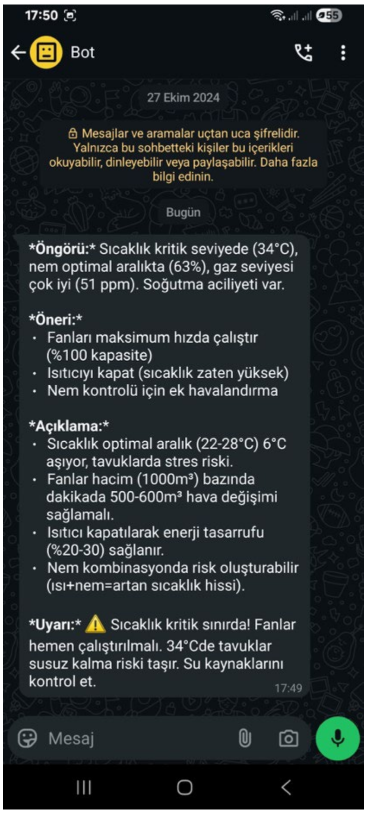
Şekil 4. Node-RED iş akış şeması

Node-RED kullanıcı arayüzü, sistemdeki sensör verilerinin görselleştirilmesi ve kullanıcıların kümes ortamını gerçek zamanlı izleyip kontrol edebilmesi amacıyla tasarlanmıştır. Arayüz, Node-RED Dashboard (node-red-ui) kütüphanesi kullanılarak geliştirilmiştir. Bu kütüphane, web tabanlı kontrol panelleri oluşturmak için hazır widget'lar (gauge, chart, text, slider, button vb.) sunmakta olup, kullanıcıların verileri grafikler, göstergeler ve sayısal değerler ile anlık olarak takip etmesine olanak tanır. Kullanıcı arayüzüne, Node-RED'in web tabanlı front-end adresi olan localhost:1880/ui üzerinden erişilebilmektedir. Bu yapı, sistemin hem görselleştirme hem de kontrol işlevlerini entegre bir şekilde sunmasını sağlamaktadır. Arayüz, mobil ve masaüstü cihazlarla uyumlu olup, kullanıcı dostu bir deneyim sunmaktadır.

Şekil 5. Node-RED kullanıcı arayüzü

Yapay Zekâ Entegrasyonu

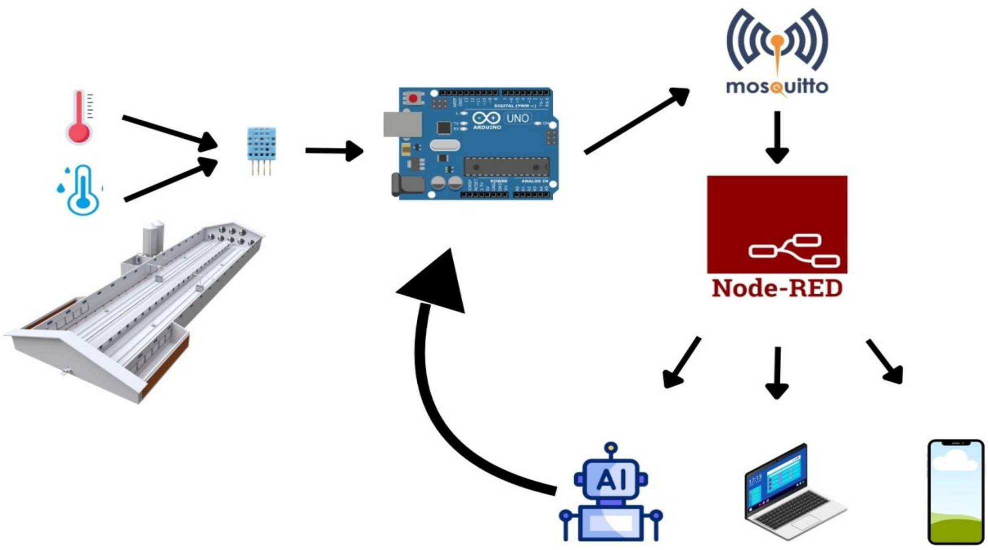
Sistem, belirli zaman aralıklarında sensör verilerini OpenRouter API aracılığıyla yapay zekâya göndermekte ve alınan yorumlar doğrultusunda fan ve ısıtıcıların açılıp kapanmasına ilişkin öneriler sunmaktadır. Bu sayede sistem, hayvanların konforunu maksimize ederek refahı artırmaktadır ve insan müdahalesine olan ihtiyacı minimize etmektedir.



Şekil 6: WhatsApp bildirimi

Sistem İşleyişi

Sistem şu şekilde çalışmaktadır: sensörler kümes ortamından verileri toplar; ESP8266 mikrodenetleyici bu verileri MQTT protokolü üzerinden Home Assistant sunucusuna iletir; Node-RED ile mantıksal işlemler ve görselleştirme yapılır; veriler MySQL veri tabanına kaydedilir; OpenRouter AI ile analiz edilen veriler, fan ve ısıtıcı kontrolünde uygulanır. Ve AI yorumu kullanıcıya mesaj olarak iletilir Bu bütünleşik yapı, kümes içi çevresel parametrelerin optimum düzeyde tutulmasını ve enerji verimliliğinin artırılmasını sağlamaktadır.



Şekil 7. Sistemin Genel Yapısı

Bulgular ve Tartışma

Maket kümes üzerinde gerçekleştirilen sistem denemelerinde, sensör verilerinin gerçek zamanlı izlenmesi ve kontrol işlevlerinin etkinliği değerlendirilmiştir. Kümes içi sıcaklık, nem ve gaz değerleri, Şekil 5'te gösterilen Node-RED kullanıcı arayüzü üzerinden takip edilmiştir. Elde edilen veriler, sensörlerin doğru ve güvenilir biçimde çalıştığını göstermekte olup, kümes ortamının kontrol altında tutulmasında sistemin yeterli performansı sağladığını ortaya koymaktadır. Fan ve ısıtıcıların otomatik kontrolünde gözlemlenen tepki süresi, sensörden veri alınması, NodeMCU üzerindeki mantıksal işlem, MQTT protokolü ile Home Assistant sunucusuna iletilmesi ve cihazlara komut gönderilmesi sürecini kapsamaktadır. Denemeler sırasında bu sürenin ortalama 3 saniye olduğu belirlenmiştir. Bu gecikme, maket düzeyindeki sistemlerde normal kabul edilebilir bir süre olarak değerlendirilmiş ve gerçek kümes uygulamalarında optimize edilebilecek bir parametre olarak tartışılmıştır. Bulgular ayrıca, IoT tabanlı sistemlerin sensör-veri entegrasyonu ile kümes ortamında hayvan refahını destekleyici bir işlev sağlayabileceğini göstermektedir. Sistemin, sıcaklık, nem ve gaz seviyelerini izleyerek fan ve ısıtıcıları kontrol etmesi, maket ortamında enerji verimliliği ve çevresel parametrelerin stabilizasyonu açısından olumlu sonuçlar ortaya koymuştur. Bu bağlamda, sistemin sensör verilerini gerçek zamanlı işleme ve kullanıcıya görsel geri bildirim sunma kapasitesi, hem hayvan konforu hem de enerji optimizasyonu açısından önemli bir avantaj sağlamaktadır. Sonuç olarak, elde edilen bulgular IoT tabanlı otomasyon sistemlerinin, özellikle hayvan refahının kritik olduğu küçük ölçekli kümes ortamlarında, çevresel parametrelerin izlenmesi ve kontrol edilmesinde etkin bir araç olduğunu göstermektedir. Sistem, veri işleme ve cihaz kontrol süreçlerindeki gecikmelerin optimize edilmesi ile daha geniş ölçekli uygulamalarda da kullanılabilir bir potansiyele sahiptir.

Çalışmanın gelecekteki geliştirme perspektifi kapsamında, AI ve makine öğrenmesi tabanlı yaklaşımlar ile maket kümes sisteminin etkinliği artırılabilir. Bu bağlamda, hayvan refahını ve üretim verimliliğini desteklemek amacıyla aşağıdakilerin yapılması planlanmaktadır.:

1.Görüntü İşleme ile Hayvan Aktivitesi: Kümes içerisindeki kameralar aracılığıyla hayvanların hareketleri izlenebilir. AI algoritmaları, aktivite düzeylerini analiz ederek hayvanların sağlık durumu ve stres seviyeleri hakkında bilgi sağlayabilir. Anormal hareketler veya düşük aktivite, erken uyarı sistemi olarak kullanılabilir.

2.Konum Takibi ile Sıcaklık ve Konfor Analizi: Hayvanların küme içerisindeki konumları izlenerek, yoğunlaştıkları bölgelerde sıcaklık veya hava akışı yetersizlikleri tespit edilebilir. Örneğin, belirli alanlarda toplanan hayvanların sobaya yakın durması, düşük sıcaklık koşullarını ve konfor ihtiyacını ortaya koyabilir.

3.Gıda ve Su Tüketimi Takibi: Otomatik yemlik ve suluklara entegre sensörler ile bireysel ve grup bazında günlük yem ve su tüketimi ölçülebilir. Makine öğrenmesi, bu verilerle anormallikleri tespit ederek beslenme dengesizliklerini ve potansiyel sağlık sorunlarını belirleyebilir.

4.Hastalık ve Anomali Tespiti: Görüntü işleme ve davranış analizi birleştirilerek hastalık belirtileri erken aşamada tespit edilebilir. Örneğin, kanatlarını sarkıtma, izole olma veya sürekli uyuma gibi davranışlar AI tarafından sınıflandırılabilir ve kullanıcıya raporlanabilir.

5.Üretim Performansı ile Refahın İlişkilendirilmesi: Yumurtlama sayısı, ağırlık artışı veya et kalitesi gibi ekonomik veriler ile hayvan refahı verileri AI tarafından ilişkilendirilebilir. Böylece hem üretim verimliliği hem de hayvan sağlığı optimize edilebilir, en uygun çevresel ve beslenme koşulları belirlenebilir.

Bu entegrasyonlar, IoT tabanlı kümes otomasyon sistemini sadece çevresel parametreleri kontrol eden bir yapı olmaktan çıkararak, hayvan refahını ve ekonomik verimliliği bütüncül bir şekilde destekleyen akıllı bir sistem haline getirebilir.

Teşekkür

Bu çalışmada bize rehberlik eden ve destekleyen Prof. Dr. Zeynel Cebeci hocamıza teşekkür ederiz.

Kaynaklar

Aydın, A. (2020). Etlik Piliç Refahının Tespitinde Yeni Nesil Teknolojik Sistemlerin Önemi. Lapseki Meslek Yüksekokulu Uygulamalı Araştırmalar Dergisi, 7(2), 47–60. https://dergipark.org.tr/tr/pub/ljar/issue/59169/810692

Durgun, Y. (2021). Nesnelerin İnterneti Teknolojisinin Kümes Ortamına Uygulanması ve Etkileri. Avrupa Bilim ve Teknoloji Dergisi, 28, 463–468. https://doi.org/10.31590/ejosat.1005685

OASIS. (2019). MQTT version 5.0. OASIS Standard. https://docs.oasis-open.org/mqtt/mqtt/v5.0/mqtt-v5.0.html

Home Assistant. (2024). Home Assistant Documentation. https://www.home-assistant.io

Oracle. (2024). Oracle VM VirtualBox User Manual. https://www.virtualbox.org

Node-RED. (2024). Node-RED Documentation. https://nodered.org/docs

Idris, M. R., et al. (2021). The IoT Practical Book using Arduino WeMos D1 R1 Microcontroller. Pinout diyagramı https://www.researchgate.net/publication/352771421_The_Internet_of_Things_IoT_Practical_Book_using_Arduino_WeMos_D1_R1_Microcontroller

Circuits4you.com. (2016). Arduino DHT11 humidity temperature sensor https://i0.wp.com/circuits4you.com/wp-content/uploads/2016/05/DHT11_Pins.png?w=516&ssl=1

Xeohacker. (2024). MQ-2 Smoke/Gas Sensor Datasheet, Pinout & Working. The Engineering Projects https://images.theengineeringprojects.com/image/webp/2024/02/mq-2-gas-sensor-4.png.webp?ssl=1

Migrations, Agricultural Production, and Food Crisis in the World

Wadah Elsheikh[1*], İlknur Uçak[2], M. Cüneyt Bağdatli[3]

[1] University of Khartoum, Faculty of Animal Production, Khartoum, Sudan
[2] Nigde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Nigde, Turkiye
[3] Nigde Ömer Halisdemir University, Faculty of Architecture, Department of City and Regional Planning, Nigde, Turkiye
[*]Corresponding Author e-mail: Wadah88@gmail.com

Abstract

Throughout history, migration—the movement of people from one country to another—has profoundly influenced society. Migration is a significant global phenomenon driven by economic, political, cultural, or environmental factors. In this review, we aim to shed light on the impact of migration on agricultural production and its role in the global food crisis. Migration is connected to food security, agriculture, and rural development. Migrants, both domestic and international, contribute to economic growth, sustainable development, poverty reduction, and food security while ensuring the basic needs of forcibly displaced individuals are met. Global migration is now a crucial source of population growth and stability, helping to counter negative growth in other regions. Rural-urban migration is a common movement, whether induced or voluntary, often associated with agricultural seasons. Advances in communication and transportation have made it easier for rural migrants to maintain connections between rural and urban areas. This highlights the significant overlap between migration and food security, which necessitates further research, particularly regarding their impact on agricultural production.

Keywords: *Food Crisis, Agricultural production, Migration, World*

Introduction

Migration, defined as the movement of individuals away from their usual residence, either within a country or across international borders, has significantly shaped societies throughout history and continues to do so today. According to the United Nations International Migration Report (2019), the number of international migrants has surged from approximately 153 million in 1990 to 272 million in 2019. Additionally, persecution, conflict, and violence have forcibly displaced 70.8 million people, including 25.9 million refugees and over 41.3 million internally displaced persons (UNHCR, 2017). Migration, whether driven by sudden events such as violent conflicts or long-term pressures like environmental changes and food insecurity, is reshaping sustainable development in many societies. While extensive research has been conducted on migration, a significant gap remains in developing integrated frameworks that capture the complex interactions and correlations between the various drivers of migration. Understanding these relationships is crucial for creating effective policies that address the causes and consequences of migration (Morales-Muñoz et al., 2022). For instance, individuals crossing the Mediterranean Sea may initially leave their home countries for economic reasons but later encounter challenges such as violent conflict and inadequate essential services in their destination countries. Similarly, refugees who initially fled war and sought refuge in countries like Greece, Jordan, Kenya, Lebanon, or Uganda often find themselves forced to move again due to limited job opportunities and insufficient infrastructure, including water, energy, and food systems. This highlights the interconnected nature of migration drivers and the necessity of comprehensive policies that address both immediate and long-term challenges migrants face (Crawley et al., 2016). While migration is driven by numerous factors, addressing its core causes can help mitigate the hardships.

The push-pull migration model suggests that various economic, political, cultural, or environmental factors drive people away from one location while attracting them to another where conditions are more favourable. Classical theories propose that migrants are pushed by low incomes in their home regions and pulled by better opportunities in wealthier areas. More recent studies indicate that migration flows are highly sensitive to income levels at the destination (Morales-Muñoz et al., 2022). For instance, Garcia (2015) applied push-pull models to internal migration patterns in sub-Saharan African countries, using census microdata, and found that this model accounted for 87% of internal migration. Supporters argue that these models effectively incorporate key drivers of migration, providing a comprehensive framework for understanding movement patterns.

However, critics contend that the approach is mainly descriptive, listing potential factors without clearly defining their interactions or influence. Additionally, predictive models may lack explanatory power, primarily when applied across different scales, such as using global climate models to explain localised migration. Others argue that the neoclassical perspective is overly simplistic, overlooking market imperfections, interactions between migration drivers, and the role of policies in shaping migration patterns (Morales-Muñoz et al., 2022). Internal migration accounts for the vast majority of migration worldwide, as people seek to relocate in search of essential services and a better quality of life.

Food security is a topic conspicuously absent from discussions on the connection between migration and development today. The present international agenda for food security shows a similar lack of concern for migration. Thus, it seems that these two global development agendas are very different. Since the links between migration and food security appear straightforward, the causes are difficult to comprehend. International migration undoubtedly impacts food security (for instance, Zimbabwean households significantly depend on remittances worldwide to buy food and other essentials). However, inside national borders, the connection between migration and food security is especially significant (Crush, 2013). Therefore, through this review, we aim to shed light on the impact of migration on agricultural production and its role in the global food crisis.

Migration

Migration has played a key role in shaping the societies we know today, making it an integral part of our history. The reasons behind migration, as well as its effects, are complex and varied. While some individuals are forced to leave their homes due to conflict or poverty, others migrate during peace, political stability, and economic growth. People may also move abroad for education, to reunite with family, or to pursue employment opportunities that will support their relatives financially back home. A significant portion of international migrants come from rural communities. Both international migration and internal migration—such as the movement from rural areas to urban centres—are critical components of economic structural transformation. These shifts create both opportunities and challenges for rural economies. For instance, remittances sent back home can significantly reduce poverty levels. However, the departure of the most active and skilled members of rural populations can sometimes harm sectors such as agriculture. (FAO, 2018). As economies develop and undergo a structural transformation, there is a noticeable shift of labour from agriculture to other sectors, such as manufacturing and services. This transition often involves the movement of people from rural to urban areas, leading to a decline in agriculture's contribution to a nation's gross domestic product (GDP) and overall employment. However, the patterns of structural transformation and urbanisation vary across countries. In some cases, countries promote the shift of labor from agriculture to non-farm activities within rural areas or small towns, many of which were once rural communities that have grown and evolved. In contrast, other nations have seen rapid population concentration in large megacities (Christiaensen & Todo, 2013).

Most migrants relocate within their own countries, though comprehensive data on internal migration remains limited. According to the 2009 Human Development Report, over 10% of the global population had migrated internally, while international migrants—those who move across national borders—accounted for roughly 3% of the world's population. Many individuals opt for internal migration over international relocation due to the high costs of long-distance travel and prefer to stay in areas with similar language and cultural backgrounds. For instance, in 2015, China had 247 million internal migrants, surpassing the total number of international migrants worldwide, which stood at 244 million. By 2017, the number of international migrants had risen to 258 million, with approximately 64% residing in high-income countries. However, many regions' most significant international migration flows occur within the same geographic area (United Nations, 2017). By 2014, approximately 54% of the global population resided in urban areas, up from 43% in 2000. Nearly half of these urban residents live in smaller cities with populations under 500,000, while only about one in eight are located in the world's 28 megacities, each of which houses over 10 million people. North and Latin America are the most urbanized regions globally, with 82% and 80% of their populations living in urban settings, respectively. In contrast, Africa and Asia still have significant rural populations, with approximately 60% and 52% of their people living in rural areas. However, economic growth drives increased rural-to-urban migration in many countries (United Nations, 2014). For instance, China has undergone a rapid structural transformation, reducing its rural population from 80% to 55% over the past two decades. By the end of 2012, China had over 260 million internal labor migrants, accounting for 19% of the population, despite policies discouraging such movement. Similar migration patterns are evident in Korea, Vietnam, and Thailand. Africa is also experiencing rapid urbanization; in South Africa, nearly half of all internal migrants settle in just five out of 52 metropolitan districts. Meanwhile, in countries like Niger, most people still live in rural areas, reflecting slower structural changes (FAO, 2018).

Migrations, Agricultural Production, and Food Crisis in the World

Projections suggest that by 2050, 66 % of the global population will reside in urban areas. Asia and Africa are expected to urbanize rapidly, with urban populations reaching 56% and 64%, respectively. While rural-to-urban migration plays a crucial role in development by allowing people to benefit from urban economic opportunities, rural-to-rural migration remains common in many developing nations. This type of migration is often less expensive and requires fewer new skills. For example, between 1999 and 2000, rural-to-rural migration accounted for approximately 62% of all population movements in India, a trend also observed in several sub-Saharan African countries during the 1990s (United Nations, 2014). Improvements in transportation and communication have made it easier for rural migrants to move and maintain connections between rural and urban areas. Migration is often not a one-time, permanent move; many first-generation migrants retain strong ties to their hometowns and engage in circular migration, frequently linked to agricultural seasons. In Africa, for example, households are often described as fluid, with members moving between rural and urban areas depending on the time of year. In South Africa, circular migration is the dominant form of migration, and seasonal, circular, and short-term movements are common throughout the continent, often recurring over time within and across national borders (FAO, 2018). Migration decisions fall along a spectrum from voluntary to forced movements. Voluntary migration typically involves proactive, planned relocations aimed at improving living conditions, such as moving abroad for education, family reunification, or better job opportunities. In contrast, forced migration is a last resort in response to threats to safety, security, or livelihoods. This type of migration is often triggered by war, civil conflict, natural disasters (such as floods, hurricanes, or earthquakes), or development projects like mining, large-scale agriculture, deforestation, and infrastructure construction, which can displace local populations (FAO, 2017). Around half a billion people reside in 19 countries experiencing protracted crises, with approximately 129 million facing chronic hunger. Food insecurity is a defining characteristic of these crises, often forcing migration as a survival strategy rather than a voluntary decision. When people lose access to essential resources and assets needed for food production, they have little choice but to relocate. In these contexts, migration is rarely an informed choice but rather a necessity to escape conflict, extreme poverty, and deteriorating livelihoods (FAO, IFAD, IOM, WFP, 2018).

There is limited understanding of how migration influences agricultural management practices and farmers' risk responses. Some studies suggest that migration can provide households with essential resources—such as knowledge and financial capital—that support on-farm adaptation. However, there is insufficient evidence to establish these connections fully. This gap is especially relevant for rural households in South Asia, where migration often plays a key role in their overall risk management strategy (Solomon et al., 2024). Improving agricultural production efficiency and resolving labour shortages are crucial tactics for maximising the urban-rural dual economic structure through the movement of agricultural surplus labour. The repercussions of labour mobility are not limited to cities; they also affect neighbouring areas since they frequently transcend metropolitan boundaries. This movement enhances labour allocation efficiency in receiving areas, lessens resource mismatches, and balances regional development (Lee et al., 2022). Furthermore, migrant workers' remittances support the accumulation of wealth in rural communities, which promotes technical advancement and agricultural innovation. A broader regional spillover effect may result from the increased ability of nonagricultural income to impact industry strategy and governmental regulations. Nevertheless, the majority of current research focuses on effects at the macro level, with limited investigation of the regional ramifications and spatial aspects of agricultural labor movement (Du et al., 2024). A recent study examining eight developing countries—Guatemala, Peru, Ghana, Tanzania, Bangladesh, India, Thailand, and Vietnam—suggests that climate factors influence migration by affecting agricultural productivity and food security at the household level. The impact of climatic stressors on migration decisions depends on a household's resources, including land quality, skills, and the ability to mitigate climate risks through income diversification, altered food consumption, and access to social safety nets. For more resilient households, migration serves as one of many adaptation strategies. However, the most vulnerable households, lacking alternative livelihoods, assets like land, and essential skills, often resort to migration to survive (Rademacher-Schulz et al., 2014). Evidence from rural Savannah communities in northern Ghana indicates migration responds to declining crop yields, reduced livestock production, and rising food prices. During the dry season, migration to more fertile lands or mining sites becomes a crucial livelihood strategy to cope with food insecurity. Inadequate rainfall in rural areas leads to lower agricultural output, which increases hunger and prompts households to migrate in search of food security. A qualitative study further confirms the link between food insecurity, adverse climatic events, and migration in these Central American countries. While poverty and unemployment remain the primary drivers of emigration, reduced agricultural productivity, droughts, crop-destroying pests, and widespread violence contribute significantly (FAO, IFAD, IOM, WFP., 2018).

Returnees play a crucial role in developing their countries of origin through remittances, capital investments, and technology transfers. Their contributions extend beyond financial support to include knowledge sharing, philanthropy, and creating social and economic networks. Migrants often invest in micro, small, and medium enterprises in their home and host countries, helping stimulate economic growth and job creation. Additionally, they build international trade relationships, reducing market entry barriers by leveraging their understanding of local laws, regulations, and consumer preferences. These activities help lift families out of poverty and foster stronger economic ties between the origin and host countries (Ratha et al., 2011). Migration contributes to the development of societies through intermingling migrants with local populations. Returnees play a crucial role in developing their countries of origin through remittances, capital investments, and technology transfer.

Conclusion

The relationship between agricultural productivity and migration has a significant impact on food security. Millions of people have been displaced both domestically and internationally due to economic instability, wars, and global climate change, which has disrupted food production and depleted resources. Instability and decreased agricultural yield are the results of these difficulties. Everyone is now concerned about migration, and governments, international organisations, and local communities must collaborate to develop flexible policies that improve food security and safeguard the rights and means of subsistence of migrants. Achieving global food stability in the face of growing migratory pressures will require a long-term vision and ongoing international collaboration for sustainable development and global food security.

References

Christiaensen, L. & Todo, Y. (2013). Poverty Reduction during the Rural-Urban Transformation: The Role of the Missing Middle. Policy Research Working Paper; no. WPS6445. Washington DC, World Bank.

Crush, J. (2013). Linking food security, migration and development. *International migration*, *51*(5), 61-75.

Du, Y., Zhao, Z., Liu, S., & Li, Z. (2023). The impact of agricultural labor migration on the urban–rural dual economic structure: The case of Liaoning province, China. *Land*, *12*(3), 622.

FAO (2018). The Linkages between Migration, Agriculture, Food Security and Rural Development. Rome. 80pp. (available at http://www.fao.org/3/CA0922EN/CA0922EN.pdf).

FAO IFAD IOM WFP. (2018). The Linkages between Migration, Agriculture, Food Security and Rural Development. Rome. 80pp. (http://www.fao.org/3/CA0922EN/CA0922EN.pdf). Licence: CC BY-NC-SA 3.0 IGO

FAO. (2016). Addressing Rural Youth Migration at its Root Causes: A Conceptual Framework. Social Policies and Rural Institutions Division. Rome, FAO. 74 pp. (available at http://www.fao.org/3/a-i5718e.pdf)

Garcia, A. J., Pindolia, D. K., Lopiano, K. K., & Tatem, A. J. (2015). Modeling internal migration flows in sub-Saharan Africa using census microdata. *Migration studies*, *3*(1), 89-110.

Li, L., Khan, S. U., Guo, C., Huang, Y., & Xia, X. (2022). Non-agricultural labor transfer, factor allocation and farmland yield: Evidence from the part-time peasants in Loess Plateau region of Northwest China. *Land Use Policy*, *120*, 106289.

Morales-Muñoz, H., Jha, S., Bonatti, M., Alff, H., Kurtenbach, S., & Sieber, S. (2020). Exploring connections—Environmental change, food security and violence as drivers of migration—A critical review of research. *Sustainability*, *12*(14), 5702.

Rademacher-Schulz, C., Schraven, B., & Mahama, E. S. (2014). Time matters: shifting seasonal migration in Northern Ghana in response to rainfall variability and food insecurity. *Climate and Development*, *6*(1), 46-52.

Ratha, D., Mohapatra, S., Özden, C., Plaza, S., Shaw, W., & Shimeles, A. (2011). Leveraging migration for Africa: Remittances, Skills and Investments. Washington, DC, World Bank,

UNHCR (United Nations High Commissioner for Refugees). (2017). Global trends: Forced displacement in 2018.

United Nations, (2017). Department of Economic and Social Affairs, Population Division. International Migration Report 2017: Highlights (ST/ESA/SER.A/404).

Water Footprint in Food Production of Africa

Wadah Elsheıkh[1*], M. Cüneyt Bağdatlı[2]

[1]Department of Meat Production, Faculty of Animal Production, University of Khartoum, Khartoum, Sudan
[2]Department of City and Regional Planning, Faculty of Architecture, Nigde Ömer Halisdemir University Niğde, Turkiye
[*]Corresponding Author e-mail: Wadah988@gmail.com

Abstract

Water scarcity is a global issue exacerbated by population growth, economic expansion, urbanisation, industrialisation, and climate change. Africa, the second driest region, faces physical and economic water scarcity, with uneven distribution and inadequate infrastructure limiting access to water. Water resources in Africa are essential for achieving multiple Sustainable Development Goals, including poverty reduction, food security, health, and access to clean water. However, water scarcity is exacerbated by population growth and climate change, with agriculture being the largest consumer of water. Climate change and population growth are expected to worsen food insecurity. Addressing the challenge of sustaining food production under increasing water constraints is critical for many African nations. This study aims to highlight the Water Footprint in Food Production in Africa. Effective strategies include improving water use efficiency and promoting balanced diets to ensure food security and sustainable water use.

Keywords: *Africa, Water Footprint, Food Production*

Introduction

Water scarcity is increasing worldwide due to rising water demand, driven by rapid population growth, economic expansion, urbanization, industrialization, and climate change (Shtull-Trauring et al., 2016). By 2050, global water demand is projected to rise by 55%, with approximately 40% of the world's population living in areas experiencing severe water stress (Zhang et al., 2019). Africa, the second driest region in the world, faces both physical and economic water scarcity. The uneven distribution of water primarily causes physical water scarcity; for example, the annual available water per capita in North African countries such as Tunisia, Algeria, and Libya is below 500 m³. In contrast, sub-Saharan countries have water availability above the FAO-recommended threshold of 1,700 m³ (Dolan et al., 2021). Economic water scarcity, on the other hand, arises from a lack of infrastructure and poor water resource management, limiting access to water even when it is available. Many African nations struggle with inadequate human, economic, and institutional capacity to develop and sustainably manage water resources (Besada & Werner, 2015). Climate change further intensifies these challenges, worsening the existing stress on Africa's water resources (Sylla et al., 2018). By 2030, approximately 250 million Africans are expected to live in regions facing severe water stress (Naik, 2017), as water scarcity worldwide continues to increase, particularly in light of global challenges such as population growth and climate change.

The agricultural sector is the largest consumer of water globally, particularly in Africa. Approximately 70% of the world's water withdrawals are used for agriculture, with this figure exceeding 90% in certain arid and semiarid regions of Africa (El Gafy et al., 2017). Most African agriculture relies on rainfall, but the uneven distribution of rainfall poses a threat to food security (Nicholson et al., 2018). Climate change and population growth are expected to worsen food insecurity. Research indicates that a 1°C rise in global temperature could reduce crop yields in Africa's arid regions by about 10% (UNDP, 2007). With Africa's population projected to reach 2 billion by 2050 (Ezeh et al., 2020), the widening gap between water supply and demand will further strain food security. Addressing the challenge of sustaining food production under increasing water constraints is critical for many African nations. Population growth and climate change have exacerbated Africa's water scarcity issues. Given that agriculture is the most significant water consumer, a thorough understanding of the water-food relationship is crucial for mitigating water-related pressures on food security. Water footprint (WF) assessments and breakdowns offer valuable insights for policymakers in planning effective water management strategies (Tuyishimire et al., 2022).

This rising demand is further intensified by climate change and population growth. However, reports suggest that the availability of arable land will be insufficient to meet these demands in the coming years. As a result, efforts to enhance food production through innovative methods have gained the attention of crop biotechnologists (Fanzo et al., 2018). Recent technological advancements and developments have played a crucial role in addressing challenges related to sustainable development and food security, ultimately contributing to improved agricultural yields (Kou et al., 2018). The agricultural sector is the largest water consumer in Africa, primarily dependent on traditional rainfed farming, which is highly vulnerable to extreme environmental variations such as global warming.

Water footprint research primarily measures and evaluates water usage at various global, national, and watershed levels. Most water footprint (WF) studies have focused on agricultural production, examining global WFs (Hanasaki et al., 2010), national WFs (Marston et al., 2018), and regional or basin-level analyses (Muratoglu, 2020). Mekonnen and Gerbens-Leenes (2020) projected that the water footprint of food consumption will rise by 22% by 2090 due to climate and land use changes, with blue water accounting for 57% of the total, leading to significant environmental impacts. Studies have also shown that dietary choices play a crucial role in determining the water footprint of food, and adopting sustainable diets can help alleviate water stress (Kim et al., 2020). Research on African countries struggling with water scarcity and malnutrition remains limited (Ercin et al., 2013). Adebiyi et al. (2021) highlighted this gap in a global review of studies on water footprints, sustainability, and productivity from 1987 to 2019. Their findings revealed extensive research in developed nations but comparatively little focus on Africa (Tuyishimire et al., 2022). Therefore, we aim to study the water footprint in food production in Africa through this review.

Water Footprint in Food Production of Africa

Food insecurity in African countries is primarily driven by insufficient food supply, often worsened by adverse climatic conditions and further intensified by climate change. Research indicates that future climate conditions will lead to declining crop yields, particularly in low-latitude regions, where even moderate temperature increases could push crops beyond their optimal growing thresholds. Rising temperatures may shorten growing seasons and increase evaporation demand, further stressing agricultural productivity (Rosenzweig et al., 2014). A reliable and sufficient water supply is essential for sustainable human development and health. However, uncertainties related to future climate change have heightened concerns about already stressed freshwater resources (Zhang & Oki, 2023). Global water demand is increasing by 1% annually, driven by population growth, economic development, and changing consumption patterns. Agriculture accounts for over 70% of global freshwater withdrawals: climate change and rapid population expansion further strain agricultural water supplies, especially in semiarid and arid regions. Given the close link between water and food security and irrigated agriculture, extensive research has been conducted to enhance water efficiency and crop yield, promoting water conservation and sustainable water management (Haris et al., 2023). Water resource management has recently emerged as a critical issue in arid regions. The water footprint index is a key metric for enabling effective and comprehensive watershed management (Sharafi et al., 2024).

The water footprint concept offers an advanced approach to analyzing the relationship between commodity consumption or production and freshwater use. The water footprint serves as a valuable indicator for assessing water supply processes. The agricultural water footprint estimates the total water consumption by crops and livestock in a specific area, encompassing blue, green, and gray water sources. The agriculture sector uses approximately 2,500 km^3 of water annually for irrigation (Fanzo, 2019). Sustainable development depends on enhancing water resource management and increasing water use efficiency. In contrast to wealthy nations, developing nations face several broad challenges related to agricultural water management, including issues related to infrastructure, pricing systems, policymaking, and the application of subsidies (Zhang & Oki, 2023). Sharafi et al. (2024) highlighted the urgent need for balanced resource management and informed decision-making in arid regions. By utilizing these insights, policymakers and stakeholders can collaborate to promote sustainable agricultural practices, safeguard water resources, ensure food security, and address environmental challenges.

The alarming projections of climate change, declining crop yields, and rising food demand pose significant challenges to food production and sustainable water management in Africa (Giordano et al., 2023). Tuyishimire et al. (2022) analyzed the water footprint of food consumption in 23 African countries from 2000 to 2018. Using the logarithmic mean Divisia index (LMDI), they identified key driving factors: consumption structure, per capita food consumption, water intensity, and population effect. During this period, the water footprint of food consumption increased from 609.8 km^3 to 1,212.9 km^3, with an average annual growth rate of 3.7%. The population effect was the primary driver (64.6%), followed by per capita food consumption (28.3%) and consumption structure (7.1%). Cereals (46.7%) and livestock (24.4%) were the two most significant contributors to the overall increase in water footprint. The findings emphasize that managing population growth and enhancing water efficiency are key strategies for reducing water-related pressures on food consumption. However, promoting a healthier dietary structure is also essential, as Africa's current dietary energy intake remains below the global average. Additionally, nine countries in the study area face an insufficient dietary energy supply, which is expected to increase the water footprint of food as calorie intake rises and diets evolve (Tuyishimire et al., 2022). Owusu-Sekyere et al. (2016) evaluated the water footprint of milk produced and processed in South Africa using the methods outlined in the Water Footprint Assessment Manual. The study found that 1,352 cubic meters of water are needed to produce one ton of milk with 4% fat and 3.3% protein in South Africa. Most of this water (86.35%) is used to produce feed for lactating cows. The water footprint for the feed of lactating cows is approximately 85% higher than that for non-lactating cows. Green water constitutes more than 86% of the total water footprint for the feed of lactating cows. Green and blue water are the main contributors to the total water footprint of milk production in South Africa, with feed production for both lactating and non-lactating cows accounting for about 99% of total water use. Focusing on feed crops with lower water footprints and higher dry matter content is recommended to provide balanced feed rations while reducing the water footprint. Water users, managers, and livestock producers should carefully monitor green and blue water usage along the milk value chain and implement strategies to minimize these impacts. The study also found that corn, sorghum, and lucerne production under irrigation in the Greater Orange River basin is sustainable, while oats production for silage in the same region is not. The findings highlight the importance of understanding the sustainability of dairy producers' and water users' inputs, production choices, and potential policy interventions related to water use.

Hoekstra and Chapagain (2007) assessed the water footprints of Morocco, a semi-arid to arid country, and the Netherlands, a humid country. The study found that both countries import more virtual water (in the form of water-intensive agricultural commodities) than they export, making them reliant on water resources from other parts of the world. The water footprint analysis revealed that Morocco relies on external water resources for 14% of its needs, while the Netherlands depends on foreign water resources for 95%. The study also highlighted that international trade can lead to global water savings when water-intensive commodities are traded from regions with high water productivity to those with lower water productivity. For instance, if Morocco were to produce the products it imports from the Netherlands domestically, it would require 780 million m^3 per year. However, these imported products were produced with only 140 million m^3/year, resulting in a global water saving of 640 million m^3/year. Improved agricultural management offers a viable strategy for enhancing food security and adapting to climate change. Higher crop yields and more efficient water use can help reduce the vulnerability of Africa's agricultural systems. Expanding irrigation infrastructure, supported by sustainable water management, is crucial for strengthening food security across the continent. Moreover, slowing the rise in agricultural water use is of utmost importance. Any strategy to achieve this should integrate food security, socio-economic well-being, and environmental sustainability while leveraging locally available technologies, knowledge, and rural livelihoods (Giordano et al., 2023). Water is essential for life, making it crucial to adopt strategies for its conservation and waste reduction, particularly in light of global scarcity and climate fluctuations. It also plays a vital role in food security, as agriculture—heavily dependent on water—is the foundation of food production worldwide.

Conclusion

In Africa, food insecurity results from an inadequate food supply, strained by rapid population growth and climate change, which therefore taxes freshwater supplies. Effective water management, as indicated by the water footprint index, is vital since declining agricultural yields and rising food demand threaten sustainability. The water footprint of food consumption has increased primarily due to population growth.

Livestock and cereals are major contributors to this rise. Food security depends on improving agricultural management, increasing irrigation, and implementing sustainable water practices. Water conservation and climate change resilience can be achieved by combining socioeconomic and environmental factors with local technology.

References

Adetoro, A. A., Ngidi, M., Nyam, Y. S., & Orimoloye, I. R. (2021). Temporal evaluation of global trends in water footprint, water sustainability and water productivity research. *Scientific African*, *12*, e00732.

Besada, H., & Werner, K. (2015). An assessment of the effects of Africa's water crisis on food security and management. *International journal of water resources development*, *31*(1), 120-133. https://doi.org/10.1080/07900627.2014.905124

Dolan, F., Lamontagne, J., Link, R., Hejazi, M., Reed, P., & Edmonds, J. (2021). Evaluating the economic impact of water scarcity in a changing world. *Nature communications*, *12*(1), 1915. https://doi.org/10.1038/s41467-021-22194-0

El Gafy, I., Grigg, N., & Reagan, W. (2017). Water-food-energy nexus index to maximize the economic water and energy productivity in an optimal cropping pattern. *Water international*, *42*(4), 495-503.

Ercin, A. E., Mekonnen, M. M., & Hoekstra, A. Y. (2013). Sustainability of national consumption from a water resources perspective: the case study for France. *Ecological Economics*, *88*, 133-147.

Ezeh, A., Kissling, F., & Singer, P. (2020). Why sub-Saharan Africa might exceed its projected population size by 2100. *The Lancet*, *396*(10258), 1131-1133.

Giordano, V., Tuninetti, M., & Laio, F. (2023). Efficient agricultural practices in Africa reduce crop water footprint despite climate change, but rely on blue water resources. *Communications Earth & Environment*, *4*(1), 1-12. https://doi.org/10.1038/s43247-023-01125-5.

Hanasaki, N., Inuzuka, T., Kanae, S., & Oki, T. (2010). An estimation of global virtual water flow and sources of water withdrawal for major crops and livestock products using a global hydrological model. *Journal of Hydrology*, *384*(3-4), 232-244.

Haris, M., Hussain, T., Mohamed, H. I., Khan, A., Ansari, M. S., Tauseef, A., ... & Akhtar, N. (2023). Nanotechnology–A new frontier of nano-farming in agricultural and food production and its development. *Science of the Total Environment*, *857*, 159639.

Hoekstra, A. Y., & Chapagain, A. K. (2007). The water footprints of Morocco and the Netherlands: Global water use as a result of domestic consumption of agricultural commodities. *Ecological Economics*, *64*(1), 143-151. https://doi.org/10.1016/j.ecolecon.2007.02.023

Kim, B. F., Santo, R. E., Scatterday, A. P., Fry, J. P., Synk, C. M., Cebron, S. R., ... & Nachman, K. E. (2020). Country-specific dietary shifts to mitigate climate and water crises. *Global environmental change*, *62*, 101926.

Marston, L., Ao, Y., Konar, M., Mekonnen, M. M., & Hoekstra, A. Y. (2018). High-resolution water footprints of production of the United States. *Water Resources Research*, *54*(3), 2288-2316.

Mekonnen, M. M., & Gerbens-Leenes, W. (2020). The water footprint of global food production. *Water*, *12*(10), 2696.

Muratoglu, A. (2020). Assessment of wheat's water footprint and virtual water trade: a case study for Turkey. *Ecological processes*, *9*, 1-16.

Naik, P. K. (2017). Water crisis in Africa: myth or reality?. *International journal of water resources development*, *33*(2), 326-339.

Nicholson, S. E., Funk, C., & Fink, A. H. (2018). Rainfall over the African continent from the 19th through the 21st century. *Global and planetary change*, *165*, 114-127.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., ... & Jones, J. W. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the national academy of sciences*, *111*(9), 3268-3273.

Scheepers, M. E., & Jordaan, H. Water Footprint of Milk Produced and Processed in South Africa: Implications for Policy-Makers and Stakeholders along the Dairy Value Chain. *Water*, *8*(8), 322. https://doi.org/10.3390/w8080322

Sharafi, S., Nahvinia, M. J., & Salehi, F.(2024). Assessing the Water Footprints (WFPs) of Agricultural Products across Arid Regions: Insights and Implications for Sustainable Farming. *Water*, *16*(9), 1311. https://doi.org/10.3390/w16091311

Shtull-Trauring, E., Aviani, I., Avisar, D., & Bernstein, N. (2016). Integrating high resolution water footprint and GIS for promoting water efficiency in the agricultural sector: A case study of plantation crops in the Jordan Valley. *Frontiers in Plant Science*, *7*, 1877. https://doi.org/10.3389/fpls.2016.01877

Sylla, M. B., Pal, J. S., Faye, A., Dimobe, K., & Kunstmann, H. (2018). Climate change to severely impact West African basin scale irrigation in 2 C and 1.5 C global warming scenarios. *Scientific reports*, *8*(1), 14395. https://doi.org/10.1038/s41598-018-32736-0

Tuyishimire, A., Liu, Y., Yin, J., Kou, L., Lin, S., Lin, J., Kubwimana, J. J., Moharrami, K., & Simbi, C. H. (2022). Drivers of the increasing water footprint in Africa: The food consumption perspective. *Science of The Total Environment*, *809*, 152196. https://doi.org/10.1016/j.scitotenv.2021.152196

UNDP. (2008). *Human Development Report 2007-2008: Fighting Climate Change: Human Solidarity in a Divided World*. UN.

Zhang, C. Y., & Oki, T. (2023). Water pricing reform for sustainable water resources management in China's agricultural sector. *Agricultural Water Management*, *275*, 108045.

The Effect of Climate Change and Global Warming on Animal Welfare in Pakistan

Maliha Afreen[1*], İlknur Uçak[2], M. Cüneyt Bağdatli[3]

[1]University of Veterinary and Animal Science, Lahore, Pakistan
[2]Nigde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Nigde, Turkiye
[3]Nigde Ömer Halisdemir University, Faculty of Architecture, Department of City and Regional Planning, Niğde, Turkiye
[*]Corresponding Author e mail: malihaafreen120@gmail.com

Abstract

Pakistan is an agricultural country and its economy especially in rural areas mostly depends on the agriculture production including livestock sector output. Livestock provides food security in both urban and rural and urban areas and helps to reduce poverty by selling animals and their food products. However, because Pakistan has a tropical climate, so it is more affected by climate change. This climate change directly or indirectly affects the Livestock sector. In this article we discuss how livestock is an important sector in terms of food security and economically beneficial in Pakistan. These climate change factors involve water scarcity, heat stress, drought stress and floods which can decrease the livestock production. Livestock products include milk, butter, meat and eggs will also decrease automatically which leads to the loss of food security. Climate change also can cause many diseases and mortalities in animals which leads to great economy loss for rural families in Pakistan. It also affects the feed sources of livestock like deficiency in grass nutrient level and loss of vitamins and minerals in crops productivity and quality. There should be proper management and strategies to mitigate the effects of climate change and to increase livestock production in Pakistan.

Keywords: *Climate change, Tropical, Livestock, Food security, Economy*

Introduction

Pakistan is the sixteenth most susceptible country to climate change (Maplecroft, 2010). As the foundation of the economy, the agricultural sector including livestock is more likely to be affected by environmental change. Pakistan is at risk from climate change, which has serious geopolitical ramifications and is caused by several reasons, including fast industrialization and urbanization. The nation has mild weather and is in a tropical area. Over the past 20 years, Pakistan has been listed as one of the top 10 nations most impacted by climate change. Climate change has had two effects on livestock:

(i) it influenced the production of fodder, and
(ii) it had a direct impact on the animals' household in various production methods.

The losses incurred by the animals in past years were caused by both heat stress and natural calamities. The worst drought episode (1998–2002) in Cholistan and Tharparkar is one of the causes of climate change in the nation. Other factors include the extreme heat wave that hit Karachi in 2015, the effects of consecutive floods since 2010, the severe winds that hit Islamabad in June 2016, the rise in landslides and Glacial Lake Outburst Floods in the country's northern regions, and an increase in cyclonic activity.

According to Rosegrant et al. (2009), livestock accounts for 17% of global calorie consumption and 33% of protein consumption, demonstrating its contribution to food and nutritional security worldwide. Since animals are allocated more fairly than land, increasing livestock production may have a greater positive impact on reducing poverty as compared to crop output (Birthal et al., 2003). Meanwhile a large percentage of rural farm households rely on livestock for their livelihood and livestock income makes up a sizable portion of farm households' income portfolios in developing nations, climate change is predicted to have a substantial impact on over 600 million people who rely on livestock for their livelihood (Thornton, 2002).

Livestock products provide a substantial contribution to the food security of both rural and urban populations in South Asian nations such as China, Bangladesh, India, and Pakistan. Pakistan's rural economy depends heavily on livestock, which accounts for 11.4% of the country's total GDP and around 58.3% of agricultural value added (Government of Pakistan, 2018). Over 8 million people in Pakistan raise cattle, and they typically make over 35% of their income from this activity (Government of Pakistan, 2018).

According to the Government of Pakistan (2016/17), the livestock industry contributed around 1,333 billion rupees to the gross value addition, demonstrating the essential role that livestock may play in reducing poverty and boosting foreign currency earnings. It was observed that food safety in Pakistan is positively correlated with the amount of milk and animals per person and working animals per acre (Mahmood et al., 2014). Similarly Ali & Khan (2013) used the propensity score matching approach to calculate the potential impact of livestock ownership on the food security of individual households in Pakistan. The results showed that the level of food security was higher for households with livestock than for those without livestock.

Animals are a major source of income for many Pakistan's small farmers. According to Khan et al. (2019), livestock is also essential for supplying the basic food needs of many households. By keeping most consistent average growth rate of about 3%, livestock now accounts for a significant portion of the agriculture industry (60.6%) (Ministry of Finance Pakistan, 2020). Pakistan's agricultural GDP is positively and significantly correlated with the production of milk, fats, eggs, bones, and mutton (Rehman et al., 2017). The four most significant livestock species in Pakistan are cattle, buffalo, sheep, and goats. During the last three years, from 2018 to 2021, cattle and goats grew at greater rates than buffalo and sheep (Ministry of Finance, Pakistan, 2020).

According to Hussain et al. (2017), Pakistan is home to the second-largest buffalo population in the world, with over 60% of the nation's buffaloes living in Punjab province (Afzal, 2009). After buffalo, which accounts for 60.24 % of milk and its byproducts, cattle are the second most important animal in terms of output providing people with vital amino acids (Ministry of Finance Pakistan, 2020; Górska-Warsewicz et al., 2018).

Humans have relied on cattle for sustenance since the beginning of farming, yet there is still a significant supply and demand imbalance because of climate change effects, which results in food insecurity. Over 1.3 billion people rely on the cattle industry (World Bank, 2020). Acosta (2018) found that approximately 0.82 billion people worldwide and over 13% of individuals in developing countries suffer from severe malnutrition. Here is the description of how climate change in Pakistan impacts on livestock production.

Impact of Climate Change on Livestock

Pakistan had ample water from the rivers that flowed through it, and its irrigation system was completely functional. However, in recent years, there has rarely been enough water to fulfill end customers' needs. The irrigation system was beginning to experience previously unheard-of strain due to population increase (UN, 2001). Droughts have a significant impact on livestock populations, and throughout the past ten years, particularly in 2003–04, their growth has decreased (SBP, 2003-04). According to Balochistani experts, the country has been plagued by drought, with the province of Balochistan being the most severely impacted and suffering fatalities (Shafiq & Kakar, 2007). These ideas were supported by a recent FAO (2012) study that detailed how the flood in the Sindh region killed 116,000 cattle heads. Floods have negatively impacted the nation in recent years, particularly in Punjab and Sindh, because of changes in precipitation patterns.

Extended drought lengthens the dry season for dairy cattle, which lowers milk production (Maurya, 2010). It is projected that roughly 64% of the world's population will experience water distress due to rising demand for water from competing sources and climatic change-induced depletion of water resources, which will ultimately result in less water available for the livestock industry (Rosegrant et al., 2009). Additionally, it is anticipated that animals would use more water because of the temperature increase (Nardone et al., 2010). Due to changes in the nutritional composition of the forage, climate change-induced heat stress also lowers livestock product output (Seerapu et al., 2015; Thornton et al., 2009).

In addition to causing a decline in cattle productivity, the changing climate also raises the incidence of livestock illnesses and mortality (Jones & Thornton, 2009; Thornton et al., 2009; Amin et al., 2010; Herrero et al., 2010; McDermott et al., 2010; Nardone et al., 2010; Rojas-Downing et al., 2017). Globally, cattle illnesses brought on by climate change are becoming more prevalent, endangering the food security, livelihood, and income of those residing in developing nations.

Impact of Climate Change on sources of Livestock Feed

Climate change may have a significant impact on the amount and quality of animal feed. Fereja (2016) claims that patterns of high temperatures and humidity have a significant impact on the amount and quality of pasture, upsetting the global cattle food cycle. Global warming has been shown to have a significant impact on grass

nutrient levels (Nardone et al., 2010), which has a negative effect on cattle productivity (Hidosa & Guyo, 2017; Das, 2017).
According to several studies, extreme weather events like high temperatures have a detrimental effect on the cattle business by reducing crop quality and quantity. Crops including wheat, maize, rice, sugarcane, and many more may have lower amounts of proteins, carbs, and several other minerals and vitamins (Myers et al., 2014; Augustine et al., 2018).

Conclusion and Recommendations

Climate change poses a serious threat to the entire planet because of its many facets and consequences on humans, animals, plants, and the ecosystem. According to previously published research, livestock health is impacted both directly and indirectly by changes in regional or global climatic patterns brought on by climate change. Therefore, it is highly advised that appropriate long-standing reworking strategies and extenuation options for the livestock sector be developed to manage climate change. It is also advised to create and implement a practical technique to connect climatic data with animal disease surveillance systems.

References

Afzal, M. (2009). Improving veterinary service in Pakistan. *Pakistan Veterinary Journal*, *29*(4).

Ali, A., & Khan, M. A. (2013). Livestock ownership in ensuring rural household food security in Pakistan. *Journal of Animal and Plant Sciences, 23*(1): 313-8.

Amin, H., Ali, T., Ahmad, M., & Zafar, M. I. (2010). Gender and development: roles of rural women in livestock production in Pakistan. *Pakistan Journal of Agricultural Sciences*, *47*(1), 32-36.

Augustine, D. J., Blumenthal, D. M., Springer, T. L., LeCain, D. R., Gunter, S. A., & Derner, J. D. (2018). Elevated CO 2 induces substantial and persistent declines in forage quality irrespective of warming in mixedgrass prairie. *Ecological Applications*, *28*(3), 721-735.

Birthal, P. S., Deoghare, P. R., & Riyazuddin, S. K. (2003). Development of small ruminant sector in India. *Project report submitted to Indian Council of Agricultural Research (ICAR), New Delhi, India*.

Acosta, A. (2018). World livestock: transforming the livestock sector through the sustainable development goals. In *World livestock: transforming the livestock sector through the Sustainable Development Goals*. Rome: Food and Agriculture Organization of the United Nations.

FAO (2012). Executive Brief; Pakistan Flood 2011. http://www.fao.org/fileadmin/templates/ tc/tce/pdf/Executive_ Briefs/24.01.12 Pakistan_Floods_FAOEB.pdf

Fereja, G. B. (2016). The impacts of climate change on livestock production and productivity in developing countries: a review. *International Journal of Research-Granthaalayah*, *4*(8), 181-7.

Government of Pakistan (2016/17). Economic Survey of Pakistan. Ministry of Finance, Government of Pakistan, Islamabad, Pakistan. http://www.finance.gov. pk/survey_1617.html.

Government of Pakistan (2018). Board of Investment, Prime Minister's Office, Government of Pakistan. Accessed from. http://boi.gov.pk/Sector/SectorDetail.aspx? sid¼1. (Accessed 28 August 2018).

Herrero, M., Thornton, P. K., Notenbaert, A. M., Wood, S., Msangi, S., Freeman, H. A., & Rosegrant, M. (2010). Smart investments in sustainable food production: revisiting mixed crop-livestock systems. *Science*, *327*(5967), 822-825.

Hidosa, D., & Guyo, M. (2017). Climate change effects on livestock feed resources: A review. *Journal of Fisheries & Livestock Production, 5*(4), 259.

Hussain, T., Babar, M. E., Ali, A., Nadeem, A., Rehman, Z. U., Musthafa, M. M., & Marikar, F. M. (2017). Microsatellite based genetic variation among the buffalo breed populations in Pakistan. *Journal of veterinary research*, *61*(4), 535.

Jones, P. G., & Thornton, P. K. (2009). Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. *Environmental Science & Policy*, *12*(4), 427-437.

Khan, K., Uthal, B., Xiangyu, G., & Bunnika, P. (2019). The Relationship between Livestock Income and Food Security: A Case Study of Jhal Magsi, Balochistan, Pakistan. *www. https://core. ac. uk/download/pdf/234683434. pdf (assessed 20 June 2021)*.

Mahmood, H. Z., Hussain, I., Iftikhar, S., Khan, M., & Nisa, F. R. (2014). Role of livestock in food security: an ascertainment from Punjab Pakistan. *International Journal of Academic Research in Business and Social Sciences*, *4*, 458-470.

Maplecroft (2010). Big economies of the future. http://maplecroft-/;989.com/about/ news/ccvi.html

Maurya, R. K. (2010). *Alternate dairy management practices in drought prone areas of Bundelkhand Region of UP* (Doctoral dissertation, IVRI, Izatnagar).

McDermott, J. J., Staal, S. J., Freeman, H. A., Herrero, M., & Van de Steeg, J. A. (2010). Sustaining intensification of smallholder livestock systems in the tropics. *Livestock science*, *130*(1-3), 95-109.

Ministry of Finance (2020). Finance division, Economic advisor's wing, Government of Pakistan, Islamabad, Pakistan.

Myers, S. S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A. D., Bloom, A. J., Carlisle, E., Dietterich, L. H., Fitzgerald, G., Hasegawa, T., Holbrook, N. M., & Usui, Y. (2014). Increasing CO_2 threatens human nutrition. *Nature*, *510*(7503), 139-142.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S., & Bernabucci, U. (2010). Effects of climate change on animal production and sustainability of livestock systems. *Livestock science*, *130*(1-3), 57-69.

Rehman, A., Jingdong, L., Chandio, A. A., & Hussain, I. (2017). Livestock production and population census in Pakistan: Determining their relationship with agricultural GDP using econometric analysis. *Information Processing in Agriculture*, *4*(2), 168-177.

Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate risk management*, *16*, 145-163.

Rosegrant, M. W., Fernández, M. A. R. I. A., Sinha, A. N. U. S. H. R. E. E., Alder, J. A. C. K. I. E., Ahammad, H., Fraiture, C. D., & Yana-Shapiro, H. (2009). Looking into the future for agriculture and AKST.

Das, S. (2017). Impact of climate change on livestock, various adaptive and mitigative measures for sustainable livestock production. *Approaches Poultry and Dairy & Veterinary. Sciences*, *1*, 64-70. https://doi.org/10.31031/ APDV. 2017.01.000517

SBP (2003-04). Annual Report. State Bank of Pakistan, Islamabad.

Seerapu, S. R., Kancharana, A. R., Chappidi, V. S., & Bandi, E. R. (2015). Effect of microclimate alteration on milk production and composition in Murrah buffaloes. *Veterinary world*, *8*(12), 1444.

Shafiq, M., & Kakar, M. A. (2007). Effects of drought on livestock sector in Balochistan Province of Pakistan. *International Journal of Agriculture and Biology (Pakistan)*, *9*(4), 657–665.

Thornton, P. K., van de Steeg, J., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural systems*, *101*(3), 113-127.

Thornton, P., Kruska, R., Henninger, N., Kristjanson, P., Reid, R., Atieno, F., Odero, A., Ndegwa, T., 2002. Mapping Poverty and Livestock in the Developing World. International Livestock Research Institute (ILRI), PO Box 30709, Nairobi, Kenya.

Thornton, P. (2002). *Mapping poverty and livestock in the developing world* (Vol. 1). ILRI (aka ILCA and ILRAD).

UN (2001). Resident Coordinator of the UN Systems' Operational Activities for Development in Pakistan. Drought update # 13.

Górska-Warsewicz, H., Laskowski, W., Kulykovets, O., Kudlińska-Chylak, A., Czeczotko, M., & Rejman, K. (2018). Food products as sources of protein and amino acids—The case of Poland. *Nutrients*, *10*(12), 1977.

World Bank (November 19, 2020). Moving towards sustainability: The Livestock Sector and the World Bank. Washington, DC: World Bank. Available at https://www.worldbank.org/en/topic/agriculture/ brief/moving-towards-sustainability-the livestock- sector-and-the-world-bank.

The Causes and Effects of Climate Change on Decreasing Food Production in Africa

Maliha Afreen[1*], İlknur Uçak[2], M. Cüneyt Bağdatli[3]

[1]University of Veterinary and Animal Science, Lahore, Pakistan
[2]Nigde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Department of Animal Production and Technologies , Nigde, Turkiye
[3]Nigde Ömer Halisdemir University, Faculty of Architecture, Department of City and Regional Planning, Nigde, Turkiye
[*]Corresponding Author e mail: malihaafreen120@gmail.com

Abstract

Climate change becomes a major issue universally because of global warming which both are interchangeable. Global warming occurs because of pollution, deforestation and greenhouse gas emissions leading to climate change like higher temperatures, drought, floods and changing rain fall patterns. In this article we discussed about causes of climate change in Africa and their effects on food production in African countries. Extreme droughts lead towards the drying up of soil, which is not a suitable condition for agricultural crops, consequently it becomes a major reason for food insecurity. Higher temperatures create more pests' diseases in crops and livestock which also leads towards food insecurities because of loss in crops and livestock. These natural food losses also affect rural livelihoods. Fisheries also effected because of rising sea level temperatures and floods which is also a major factor of food insecurity in African region. Many waters borne diseases also spread into foods and humans due to floods which cause disturbance of food chain and human capacity to get enough nutrients from available foods. Consequently, there should be proper management of climate changes and food availability on government level to overcome the problems of food insecurity.

Keywords: *Climate change, Global warming, Agriculture, Food production, Livestock*

Introduction

Climate change is one of the biggest threats to global agricultural growth. Food production and rural livelihoods are under further strain due to the continent's weather systems' growing unpredictability and irregularity. It also has a substantial financial impact on agriculture. In many regions of the world, particularly Africa, the problems of climate change and how it affects food production are becoming more widely acknowledged. Africa is the continent extremely sensitive and most at risk from climate change, according to several research (World Bank, 2016; Liliana, 2005; Vogel, 2000; Bwalya, 2013); IPCC, 2007).

The 21st-century environmental and human problem has been attributed to climate change. Most experts, studying the possible effects of climate change, which impacted a large portion of Africa's population including rising sea levels, altered rainfall patterns, greater temperatures, and increasing climatic unpredictability. These effects of climate change are real and have potential, to affect many facets of daily life. In many regions of sub-Saharan Africa, several climate models show that agricultural food production are expected to suffer due to climate change (Al et al., 2008). One of the biggest environmental, social, and economic threats facing Africa is climate change, which is already occurring as evidenced by rising temperatures, soil drying up, increased pest and disease pressure, changes in areas that are suitable for raising crops and livestock, increased desertification in the Sahara region, floods, deforestation, and erosion (UNFCCC, 2006).

Impact of climate change on African agriculture

The 2007 study from the Intergovernmental Panel on Climate Change offers a thorough analysis of the anticipated impacts of climate change on African agriculture. Due to the combined strains of inadequate infrastructure, poverty, and governance, it predicts that Africa would be the continent most vulnerable to climate change worldwide. This century, temperatures are predicted to rise by 1.5–4ºC. Crop revenue is predicted to decline by as much as 90% by 2100, while yield reduction projections indicate a 50% decrease. Parts of the Sahara are predicted to see agricultural losses of 2-7% of GDP by 2100, whereas Western and Central Africa and Northern and Southern Africa are predicted to experience 2-4% and 0.4-1.3% losses, respectively. Sea temperature changes will have a particularly negative impact on fisheries, perhaps reducing production by 50–60%.

According to Africa's Population Emergency (2010), the population of Sub-Saharan Africa is predicted to grow from 700 million in 2007 to 1100 million in 2030 and 1500 million by 2050, with a growing urbanization trend.

Climate change and food security in Africa

Rural and pastoralist populations are at risk owing to the reduction of agricultural yields, crop failures, and livestock losses brought on by severe and protracted droughts, floods, deforestation, overgrazing, and fuelwood collection that has degraded the soil. Recurrent droughts have severely affected pastoralist areas on the border between Ethiopia, Kenya, and Somalia. The loss of livestock has caused a crisis for about 11 million people who depend on livestock for their livelihoods, and it has also led to a mass evacuation of pastoralists from drought-affected areas (IPS, 2010).

One in four households in sub-Saharan Africa lack access to enough food, according to the United Nations Development Report (United Nations, 2012). Southern Africa is particularly vulnerable to climate change, according to the IPCC (2007), and the effects might be severe, affecting many people's livelihoods. According to the IPCC (2007), climate change would cause sub-Saharan Africa's agricultural productivity to drop from 21% to 9% by 2080. According to the analysis, precipitation temperatures that rise might potentially cut stable food output by as much as 50%.

According to Rowhani et al. (2011), Tanzania's average output of rice, sorghum, and maize would decrease by 13%, 8.8%, and 7.6%, respectively, by 2050 due to the predicted 2°C increase. According to Knueppel et al. (2010), Tanzania's high levels of food insecurity are closely related to lower educational attainment. According to research by Tesso et al. (2012), Ethiopia's food production is severely hampered by climate change, with yearly production losses resulting from climatic variability rising sharply year over year. According to a 2009 assessment by the European Commission, climate change in Africa would result in lower agricultural yields, which will raise food prices and compel people to alter their patterns of production and consumption. Food security will be severely impacted by global warming, according to Schmidhuber & Tubiello (2007), who predict that between 5 and 170 million people would be in danger of famine by 2080. According to Hendriks (2005), food insecurity affects between 58% and 73% of families in South Africa, despite the country's overall food security.

Causes and effects of climate Change

Global warming and climate change are frequently used synonymously (Manstrandrea & Schneider, 2009). However, in scientific publications, climate change encompasses both global warming and all other effects of rising greenhouse gas concentrations, whereas global warming refers to rises in surface temperature. Any change in the climate over time, whether brought on by human activity or natural variability, is referred to as climate change by the Intergovernmental Panel on Climate Change (IPCC, 2001). Deforestation, ozone layer depletion, rising CO_2 and greenhouse gas emissions into the atmosphere are some of the causes of climate change (Syrquin, 2008; Manstrandrea & Schneider, 2009; Whitfield et al., 1998). Natural activities including animal respiration, volcanic eruptions, and the burning or decomposition of plants and other organic things all release carbon dioxide into the atmosphere. CO_2 is released into the atmosphere by human activities such burning solid waste, wood products, and fossil fuels to heat homes, power cars, and provide electricity (Paehler, 2007). Global warming has made droughts more severe, which reduced the amount of arable land that is available. A reduction in arable land would result in a lack of food security for many rural households who rely heavily on subsistence farming for their livelihood. Between 5 and 170 million more people are predicted to be in danger of hunger by 2080 because of global warming, which would have a substantial detrimental impact on food security (Statistical Review of World Energy, 2016).

The availability of water has a significant impact on agriculture. According to Rosenzweig & Hillel (1995), climate change would alter runoff, evaporation, rainfall, and moisture storage. Droughts began to occur in parts of tropical and subtropical Africa in the 1970s (Paehler, 2007; Syrquin, 2008). Droughts in tropical and subtropical Africa are predicted by the World Bank Group (1998) to become longer and more severe. The requirement for appropriate crop management has increased because of climate change, which causes water to escape from the soil more quickly and causes the soil to dry up quickly between rains (Southworth et al., 2000, 2002). Reduced soil productivity, food supply, and water resources may result from climate change-induced increases in the severity of droughts, floods, and shifting growing seasons (Luo et al., 1999; SWCS, 2003). In turn, this will represent suffering and mortality in the ecosystems of plants and animals.

According to the IPCC (2001), the global surface air temperature is expected to increase from 1.4 to 5.8 degrees Celsius by the year 2100 in comparison to 1990. Over the latter two decades of the 20th century, Nigeria's mean annual temperature increased by an average of 0.4 degrees Celsius in different regions of the nation (FME, 2003). Numerous areas, including agriculture, forestry, fisheries, biodiversity, water, and health, would be impacted by such changes. Conditions for the spread of illnesses and insect pests are more favorable in warmer temperatures. Changes in wind patterns can affect the transmission of fungus and bacteria that cause crop diseases as well as wind-borne pests. In most African locations, economically significant pests and illnesses may predispose livestock to greater incidences of heat stress, increased disease transmission, and potential resistance to disease management efforts. Many forms of stored food would be more susceptible to bacterial and mold development in warmer, more humid environments, which would accelerate food spoiling and pose some toxicological health risks. Furthermore, the food chain and people's physiological ability to get the nutrients they need from their diet may be impacted by the rise in water-borne illnesses in flood-prone areas, modifications to the vectors of climate-responsive pests and illnesses, and the development of new diseases (Manstrandrea & Schneider, 2009).

Conclusion and Suggestions

Investing in technology intervention is necessary to address the vulnerabilities and weaknesses in food systems as well as to prevent and manage climate hazards to food security. From agricultural production to food distribution and consumption, climate change poses a serious threat to food security in African nations. Therefore, an integrated policy strategy is required to alleviate these hazards and safeguard cattle, water supplies, and arable land from global warming. More assistance is also required for small-scale rural farmers to boost agricultural output, especially at the domestic level.

References

Africa’s population emergency, (2010 March). http://www. the daily green. com/environmental - news/latest/africa-population-47010905

Al, W., Orking, G., & Clima, O. (2008). Climate change and food security: a framework document. FAO Rome, 3.

Bwalya, M. (2013). Comprehensive Africa Agriculture Development Programme (CAADP) to reduce food security emergencies in Africa. Johannesburg: NEPAD Planning and Coordinating Agency.

European Commission, (2009). Europe Aid Co-operation Office. Food security: understanding and meeting the challenge of poverty. Publications Office of the European Union.

Federal Ministry of Environment, (2003). Nigeria's First National Communication: Under the United Nations Framework Convention on Climate Change. Ministry of Environment of the Federal Republic of Nigeria.

Hendriks, S. L. (2005). The challenges facing empirical estimation of household food (in) security in South Africa. Development Southern Africa, 22(1), 103-123. https://doi. org/10.1080/03768350500044651

Intergovernmental Panel on Climate Change (IPCC), (2007). Intergovernmental panel on climate change fourth assessment report, Cambridge University Press, Cambridge, UK.

IPCC TAR WG1, (2001). The report Climate Change 2001: The Scientific Basis. In Houghton, J. T., Ding, Y.,Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K. & Johnson, C. A. (Eds.), Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.Cambridge: University Press, ISBN 0-521-80767-0. IPS (Inter Press Service NewsAgency), (2010, July 26) Climate change and diminishing fish stocks, http.www.ipsnews.net/.

Knueppel, D., Demment, M., & Kaiser, L. (2010). Validation of the household food insecurity access scale in rural Tanzania. Public health nutrition, 13(3), 360-367. https://doi.org/10.1017/S1368980009991121

Liliana, H. (2005). The food gaps: The impacts of climate change on food production: A 2020 perspective. Universal Ecological Fund, Alexandria, VA, USA.

Luo, Y., Reynolds, J., Wang, Y., & Wolfe, D. (1999). A search for predictive understanding of plant responses to elevated CO_2. Global Change Biology, 5(2), 143-156.

Manstrandrea, M. D., & Schneider, S. H. (2009). Global Warming. Microsoft® Encarta® Online Encyclopedia.

Paehler, K. (2007). Nigeria in the dilemma of climate change. Country report. Konrad Adenauer Publications, Nigeria Office. Also available at http//www.kas.de/proj/home/pub/33/2/Document_id-11468/index.html

Rosenzweig, C., & Hillel, D. (1995). Potential impacts of climate change on agriculture and food supply. Consequences, 1(2), 23-32.

Rowhani, P., Lobell, D. B., Linderman, M., & Raman Kutty, N. (2011). Climate variability and crop production in Tanzania. Agricultural and forest meteorology, 151(4), 449-460. https://doi. org/10.1016/j.agrformet.2010.12.002

Schmidhuber, J., & Tubiello, F. N. (2007). Global food security under climate change. Proceedings of the National Academy of sciences, 104(50), 19703-19708. https://doi.org/10.1073/pnas.0701976104

Soil and Water Conservation Society (SWCS) (2003). Conservation implications of climate change: soil runoff from croplands. SWCS: Ankey, Iowa, USA. Also available at http:/ www.swcs.org/docs/climate%20change-final.pdf

Southworth, J., Pfeifer, R. A., & Habeck, M. (2002). Crop modeling results under climate change for the upper Midwest USA. In Effects of Climate Change and Variability on Agricultural Production Systems (pp. 127- 157). Boston, MA: Springer US.

Southworth, J., Randolph, J. C., Habeck, M., Doering, O. C., Pfeifer, R. A., Rao, D. G., & Johnston, J. J. (2000). Consequences of future climate change and changing climate variability on maize yields in the midwestern United States. Agriculture, Ecosystems & Environment, 82(1-3), 139-158.

Statistical Review of World Energy, (2016). BP viewed 28 November 2017. http:// www.bp.com/en/global/corporate /energy-economics/ statistical- review- of- world energy. html

Syrquin, A. (2008). EU Commission discusses soil degradation and climate change. Jerusalem Post. http:/www.jpost.com/servlet/satellite? cid

Tesso, G., Emana, B., & Ketema, M. (2012). A time series analysis of climate variability and its impacts on food production in North Shewa zone in Ethiopia. African Crop Science Journal, 20, 261-274.

The World Bank Group, (1998). Climate change and sub-Saharan Africa: issues and opportunities. Africa Region Findings No. 120. Also available at http:/www.worldbank.org/afr/findinds/ English/find120.htm

UNFCCC (2006, November 15). Former UN Secretary-General Kofi Annan, addressing the Twelfth Conference of the Parties to the UNFCCC, Nairobi, Kenya.

Vogel, C. (2000). Usable science: An assessment of long-term seasonal forecasts amongst farmers in rural areas of South Africa. South African Geographical Journal, 82(2), 107-116. https://doi.org/10.1080/03736245.2000.9713700

Whitfield, C. P., Davison, A. W., & Ashenden, T. W. (1998). The effects of nutrient limitation on the response of Plantago major to ozone. New Phytologist, 140(2), 219-230.

World Bank. (2016). Arable land (hectares per person). viewed 28 November 2017, from http://data.worldbank.org/indicator/AG.LND.ARBL.HA.PC

The Negative Effects of Global Warming on Water Resources and Agricultural Production in Darfur, Sudan

Wadah Elsheikh[1*], M. Cüneyt Bağdatlı[2] , Muhammed Kamil Öden[3]

[1]Department of Meat Production, Faculty of Animal Production, University of Khartoum, Khartoum, Sudan.
[2]Department of City and Regional Planning, Faculty of Architecture, Nigde Ömer Halisdemir University Niğde, Turkiye
[3]Department of Environmental Protection Technologies, Sarayonu Vocational School, Selcuk University, Konya, Turkiye
[*]Corresponding Author e-mail: Wadah988@gmail.com

Abstract

Global warming is an escalating environmental disaster that significantly impacts natural resources and human livelihoods, particularly in developing countries like Sudan. In Sudan, agriculture serves as the primary source of GDP, a crucial contributor to foreign exchange earnings, and a vital element of the nation's livelihood. However, current and anticipated environmental changes, such as rising temperatures, shifting rainfall patterns, and an increasing frequency of extreme weather events, lead to water scarcity, land degradation, and decreased agricultural yields. These changes profoundly affect Sudanese agricultural systems that rely primarily on rainfall and fragile water infrastructure, posing serious threats to food security, economic stability, and rural livelihoods. Therefore, this study aims to examine the adverse effects of global warming on water resources and agricultural production in Darfur. The study emphasizes climate changes over recent decades, illustrating notable shifts in temperature and precipitation that necessitate integrated adaptation strategies, including enhanced water management. Identifying key challenges and solutions can help mitigate the impact of climate change in Sudan.

Key Words: *Global Warming, Water resources, Agricultural production, Sudan*

Introduction

Global warming, marked by a rise in average temperatures, is a major environmental issue of the 21st century. Its extensive effects are felt globally, especially in developing countries with limited adaptation capacity. Sudan, in Northeast Africa, is severely impacted, with climate change affecting its ecosystems, economic stability, and human well-being. Two critical vulnerable areas in Sudan are water resources and agriculture, both of which are foundational to the economy and rural life, where most people depend on rain-fed agriculture and seasonal water sources (Elsheikh et al., 2022). Sudan's varied geography makes it highly susceptible to climate fluctuations, from desert in the north to fertile savannahs in the south. Rainfall is unpredictable, coming in short, intense bursts, complicating forecasts amid global warming. Over the decades, Sudan's temperatures have steadily risen, with projections indicating this trend will continue. These climate changes exacerbate water scarcity and impact the growing seasons and productivity of major crops. Thus, the key pillars of water availability and food production are undermined, threatening food security, livelihoods, and economic growth (Alriah et al., 2024).

Sudan's geography and climate make it highly vulnerable to the impacts of climate change. The country spans various ecological zones, from the arid Sahara to fertile savanna regions. Rainfall is unpredictable, often arriving in short, intense bursts that are increasingly difficult to forecast due to global warming. Temperatures have steadily risen, with projections indicating that this trend will continue throughout the 21st century. These changes lead to greater water scarcity and alter key crop productivity. Consequently, access to water and food production are weakening, threatening food security, livelihoods, and economic growth. Agriculture, which accounts for 30% to 40% of GDP, provides jobs for over 70% of the population. Most farming relies on rainfall, making it vulnerable to shifts in precipitation and temperature. Rising temperatures may reduce crop yields due to increased evaporation, disrupted pollination, and heightened pest pressures.

Changes in rainfall patterns can delay planting, shorten growing seasons, and cause crop failures. Even staple crops like sorghum, millet, and wheat are already showing reduced productivity in some areas because of these climate stresses (Siddig et al., 2020).

As temperatures rise, finding clean water will become more difficult due to increased evaporation (Bağdatlı & Can, 2020). The world is experiencing rising temperatures from climate change and decreasing rainfall, putting habitats at risk. To mitigate global warming, we must prevent the greenhouse effect and maintain carbon dioxide levels. Reducing carbon dioxide emissions is one solution (Bağdatlı & Can, 2019). Sudan's water resources depend mainly on seasonal rainfall and the Nile River, which flows north from the south. The country relies on groundwater, small reservoirs, seasonal rivers, and surface water. However, climate change has heightened evaporation rates and reduced precipitation in some areas, making water cycles less predictable and diminishing the reliability of surface and groundwater. Flash floods and prolonged droughts, worsened by climate change, are occurring more frequently and severely. Consequently, water availability has declined, infrastructure has suffered, water sources are contaminated, and the risk of waterborne diseases has increased (Elsheikh and Nasreldin, 2022). This study assesses the negative effects of global warming on water resources and agricultural production in Sudan (South Darfur State). Understanding these effects aids in formulating policy recommendations to reduce negative consequences and promote positive ones.

Materials and Methods

In this study, we focused on the impact of global warming on agricultural lands in Sudan. We employed standard deviation to analyze the data, which measures how much the data deviates from the mean. Higher standard deviation values indicate greater variability in the data, while lower values suggest less variability. We used linear regression to determine the monthly correlation levels among specific climate parameters, evaluating temperature, precipitation, and humidity data from 1991 to 2021, as well as sunshine hours from 1999 to 2019. For this purpose, regression analysis was applied to the data (Rezaeianzadeh et al., 2014; Salihi & Üçler, 2021).

Figure 1. The location of Research Area (Sudan)

Results and Discussions

In this study, we analyzed long-term minimum, maximum, and average temperatures (°C), precipitation (mm), humidity (%), the number of rainy days, and the number of sunny hours for Sudan. Figure 2 illustrates a graph showing variations in minimum temperature data. Temperatures ranged from a low of 15.9°C in January to a high of 24.5°C in May. The R^2 value for minimum temperature is 0.0061, indicating that actual values do not closely align with predicted values. Figure 3 illustrates a graph depicting variations in maximum temperature data. May recorded the highest maximum temperature at 37.7°C, while January and August recorded the lowest at 30°C. The R-squared value for maximum temperature is 0.0669, showing that actual measurements and predictions are not closely related. Figure 4 displays a graph for the variation in average temperature data. The highest recorded average temperature was 31°C in May, while the lowest was 22.5°C in January. The R^2 value is 0.033, indicating that the real values do not closely align with the projected values.

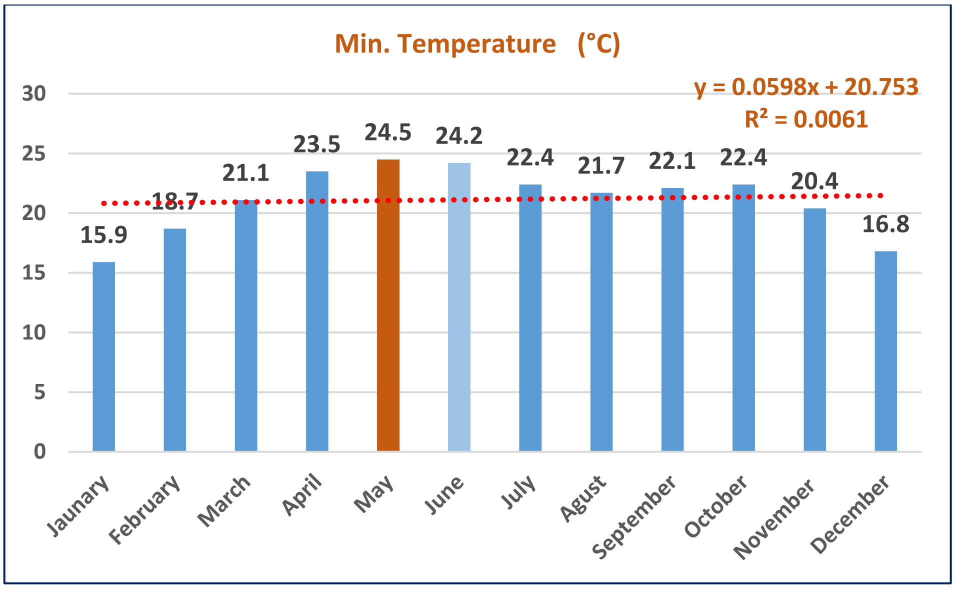


Figure 2. Distributions of Min. Temperature (1991-2021)

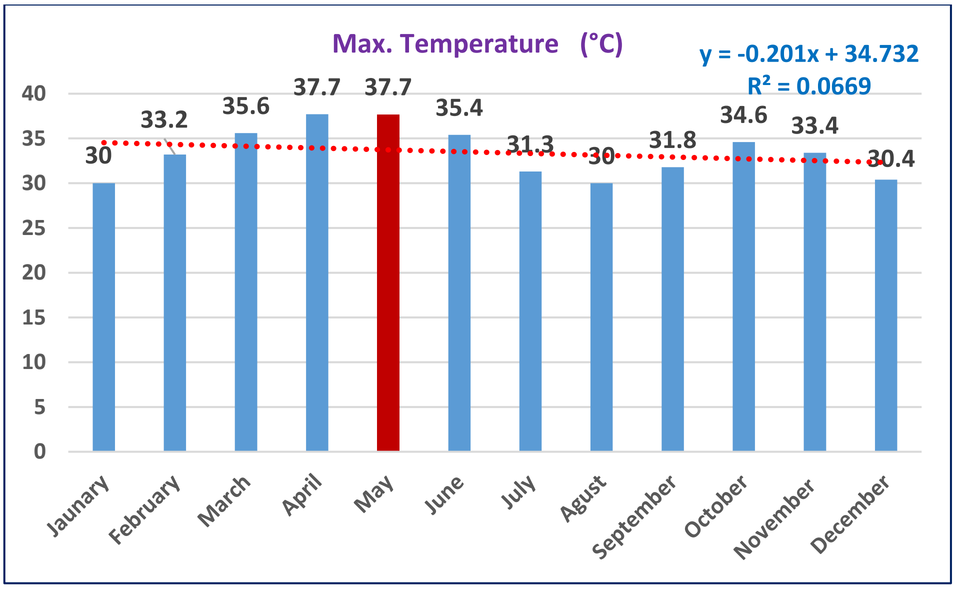


Figure 3. Distributions of Max. Temperature (1991-2021)

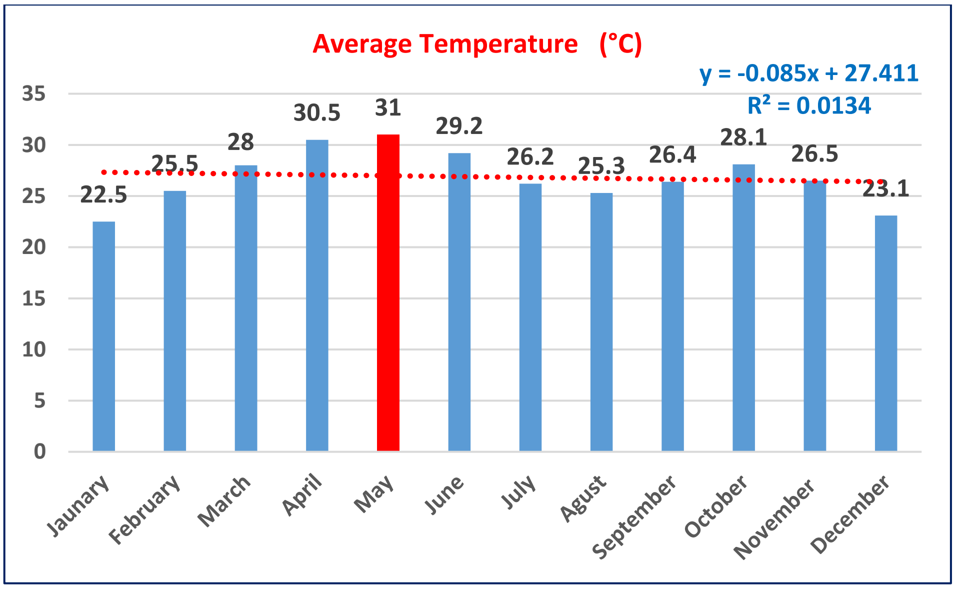


Figure 4. Distributions of Average Temperature (1991-2021)

As shown in Figure 5, the highest precipitation occurred in August, reaching 112 mm, while the lowest, at 2 mm, was recorded in April. The rainy season lasts from April through October. The R-squared value is 0.0619, indicating that the actual values do not closely align with the expected ones.
August had the highest humidity at 75%, while April had the lowest at 10% (Figure 6). The R^2 value was 0.1283, indicating that actual values are not significantly closer to expectations. Nevertheless, humidity showed better R^2 ratios compared to the other factors.
During these months, the number of rainy days shows that July had the highest recorded rainfall, with 14 days, while May and October had the lowest, with 3 days (Figure 7). The R^2 value is 0.058, indicating that the actual values do not closely align with the predictions.

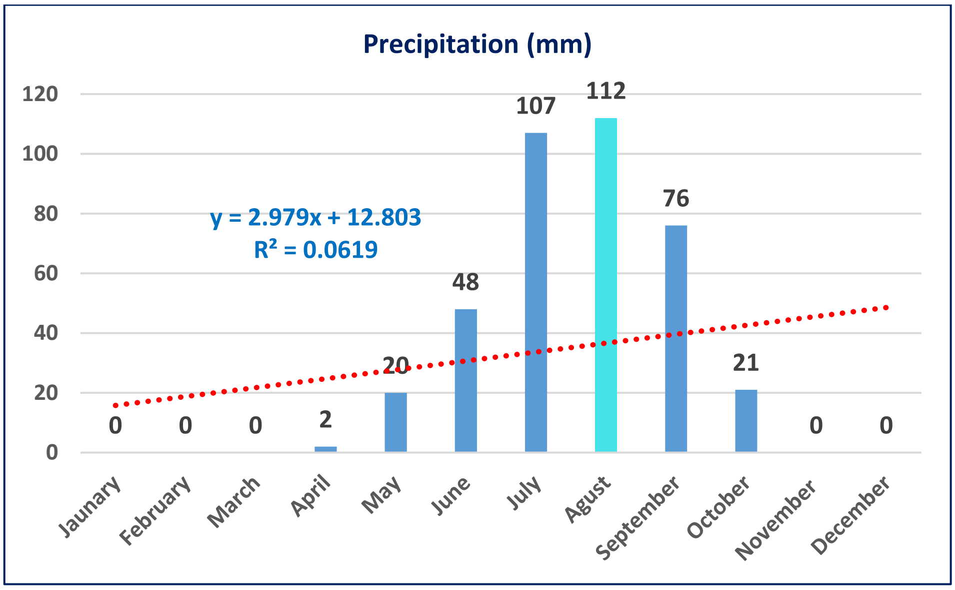


Figure 5. Distributions of Precipitation (1991-2021)

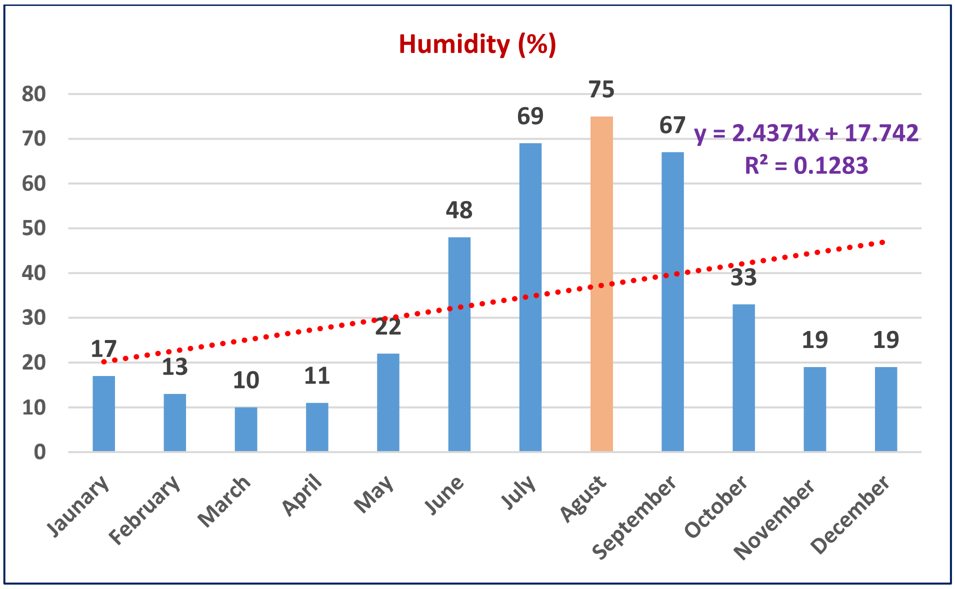


Figure 6. Distributions of Humudity (1991-2021)

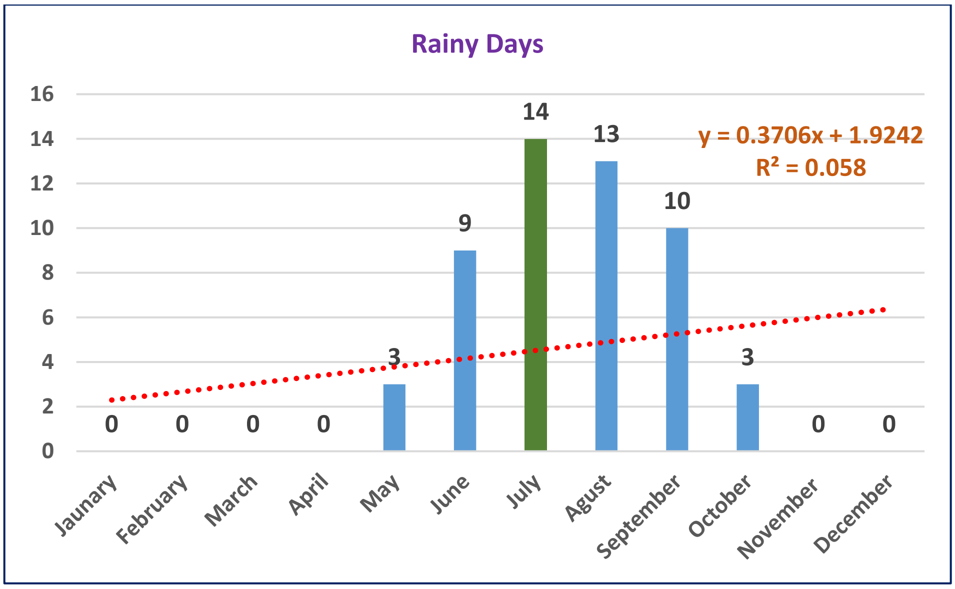


Figure 7. Distributions of Rainy Days (1991-2021)

Figure 8 illustrates the average number of sunny hours per month throughout the year.

The values range from a low of 9.5 hours in August to a high of 11.4 hours in May. Most months demonstrate fairly consistent sunny hours, with a few exceptions, particularly from April to August. A dotted red linear trendline indicates a slight upward trajectory in sunny hours over the months, but the R^2 value of 0.1523 signifies a weak correlation. The data showcases a significant seasonal variation, with minimal sunshine in January and a steady increase that peaks in June.

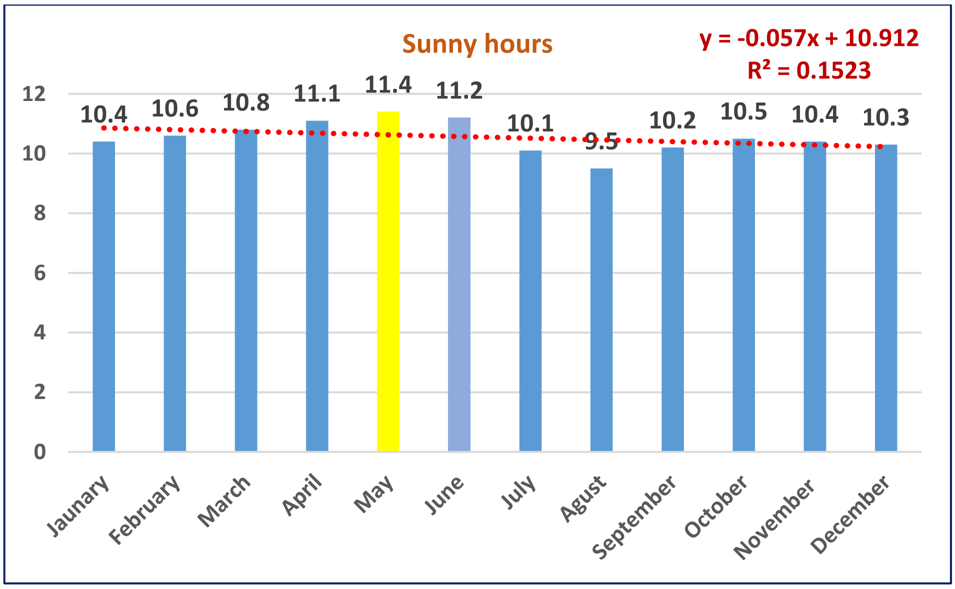


Figure 8. Distributions of Sunny hours (1999-2019)

As shown in Table 1, the average temperature is 26.86°C, the annual rainfall is 386 mm, and the number of rainy days is limited to 52 days per year. Humidity levels are low at 33.58%, and the area receives over 10 hours of sunshine each day. These conditions, worsened by global warming, exert significant pressure on water availability and heighten the vulnerability of rainfed agricultural systems. The variations in rainfall and temperature also hinder planning and productivity. Fluctuations in maximum temperature and humidity suggest that increasingly erratic climate conditions are complicating agricultural planning.

Table 1. Some statistical values of climate paremeters

Climate Paramters	Average	Standard deviation
Min. Temperature (°C)	21.14	2.7540
Max. Temperature (°C)	33.43	2.8023
Average Temperature (°C)	26.86	2.6442
Precipitation (mm) (Total)	386.00	43.1716
Humidity (%)	33.58	24.5300
Rainy Days (Total)	52	5.5487
Sunny Hours (hour)	10.54	0.5265

According to the World Bank (2015), agriculture is a vital source of income for 65% of Sudan's population and serves as the primary employer in the country. In 2011, this sector represented 47% of the labor force, with even higher numbers in rural areas, where agriculture comprises 65% of total employment, as reported by the MHRDL (2013). Consequently, the agricultural sector plays a key role in poverty reduction policies and broader economic initiatives (Siddig et al., 2020). Sudan's main crops include sorghum, cotton, groundnuts, sesame, millet, and wheat. Other agricultural subsectors, such as sugarcane, gum arabic, livestock (especially live sheep and camels), and hides and skins, are nearing their production potential. Nour & Eltayeb (2020) suggest that increased commercial agriculture can enhance income and food security, provided effective markets exist to counterbalance declines in staple crops. They recommend policies to increase crop diversity, improve irrigation, and adopt new technologies to boost agricultural productivity (Nour & Eltayeb, 2020). Mohamed (2022) analyzed the relationship between climate change, agricultural output, and food security in Sudan using time series data from 1970 to 2020. His findings reveal that the impact of climate change on food security in Sudan is complex, shaped by both climate and economic factors. The study concludes that climate change has a long-term effect on food security, rather than being determined by short-term weather conditions.

Rising temperatures and changing rainfall patterns affect the yields of both rainfed and irrigated crops, which in turn influence global and local food markets (Nelson et al., 2010). According to Siddig (2020), climate change significantly impacts Sudan's agricultural sector and economy. Evaluating scenarios that account for climate variability reveals additional risks, particularly during extreme weather years, which exacerbate economic losses and disproportionately affect low-income rural households. Although agricultural productivity may rise due to increased global demand and yields, these gains are precarious and can be easily undermined by climate variability (Siddig et al., 2020). Countries already grappling with water scarcity, such as Sudan (Siddig et al., 2020), are likely to see further declines in agricultural yields, resulting in adverse effects on rural incomes and food security (Verner and Breisinger, 2013). Climate change is expected to have an immediate, negative, and disproportionately severe impact on agriculture, the food system, and the broader economy in low-income countries throughout sub-Saharan Africa, the Middle East, and North Africa. This is primarily due to prevailing environmental conditions, limited economic diversification, and insufficient agricultural development in these regions, despite the sector's crucial role in generating export earnings and household income (Siddig et al., 2020). These factors underscore the urgent need for immediate measures to mitigate the negative impacts of climate change on agriculture and water in Sudan.

Abdo & Salih (2011) indicate that while there is immense pressure on the easily accessible water resources in Darfur, contributing to the ongoing conflict, there are sufficient water resources to meet both current and future needs. However, utilizing these resources requires significant national and external funding. To ensure effective water management in Darfur, it is crucial to implement water harvesting projects, develop groundwater resources, manage aquifer recharge in both sedimentary and fractured layers, collaboratively utilize both surface and groundwater, and integrate watershed management into valley systems. Furthermore, there is an urgent need for capacity development, research and development, monitoring networks, and a water information system (Abdo & Salih, 2011).

Conclusion

Climate change poses a significant threat to water resources and agriculture in Sudan overall, and specifically in Darfur, jeopardizing the livelihoods of millions. Understanding the connections between climate change, water scarcity, and decreasing agricultural productivity is essential for effective policymaking. This review aims to illuminate the effects of climate change in Sudan, focusing on Darfur. We explore how global warming impacts agriculture and food production in Darfur, with efforts to mitigate these effects and enhance the country's resilience to anticipated risks. This study contributes to the existing research on climate change in Sudan, highlighting potential risks.

References

Abdo, G., & Salih, A. (2011). Water resources management in Darfur. *Khartoum University Engineering Journal*, *1*(1): 41-49.

Alriah, M. A. A., Bi, S., Nkunzimana, A., Elameen, A. M., Sarfo, I., & Ayugi, B. (2024). Assessment of observed changes in drought characteristics and recent vegetation dynamics over arid and semiarid areas in Sudan. *Theoretical and Applied Climatology*, *155*(5), 3541-3561. https://doi.org/10.1007/s00704-023-04824-3

Anonymous, (2021). Climate data in Sudan, Available: https://tr.climate-data.org/afrika/sudan/al_khartum-1654/r/ocak-1/ accessed: 31.05.2025

Bağdatlı, M. C., & Can, E. (2019). Analysis of Precipitation Datas by Mann Kendall and Sperman's Rho Rank Correlation Statistical Approaches in Nevsehir Province of Turkey. *Recent Research in Science and Technology Journal,(11)*, *24*, 31.

Bağdatlı, M. C., & Can, E. (2020). Temperature Changes of Niğde Province in Turkey: Trend analysis of 50 years data. International Journal of Ecology and Development Research (IJEDR). 6(2): 62-71.

Elsheikh, W., & Nasreldin, M. (2022). Impacts of Climate Change on Water Resources in Sudan. *Eurasian Journal of Agricultural Research*, *6*(2), 83-90.

Elsheikh, W., Uçak, İ., Bağdatlı, M. C., & Mofid, A. (2022). Effect of Climate Change on Agricultural Production: A Case Study Khartoum State, Sudan. *J Agri Res*, *7*(3), 000299.

MHRDL (2013) (Ministry of Human Resources Development and Labor). Sudan Labor Force Survey 2011 (SLFS 2011). MHRDL, Khartoum, Sudan.

MHRDL (2013) (Ministry of Human Resources Development and Labor). Sudan Labor Force Survey 2011 (SLFS 2011). MHRDL, Khartoum, Sudan.

Mohamed, E. S. E. (2022). Climate change, agricultural production and food security in Sudan. *Journal of Economics and Research*, *3*(1), 1-19.

Nelson, G. C., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., ... & You, L. (2010). *Food security, farming, and climate change to 2050: scenarios, results, policy options* (Vol. 172). Intl Food Policy Res Inst.

Nour, S. M., & Mohamedain, E. (2020). Agricultural development and food Security in Sudan as seen from Kassala State.

Rezaeianzadeh, M., Tabari, H., Arabi Yazdi, A., Isik, S., & Kalin, L. (2014). Flood flow forecasting using ANN, ANFIS and regression models. *Neural Computing and Applications*, *25*, 25-37.

Salihi, P. B. A., & Üçler, N. (2021). The Effect of the Data Type on Anfis Results, Case Study Temperature and Relative Humidity. *Journal of Scientific Reports-A*, (046), 14-33.

Siddig, K., Stepanyan, D., Wiebelt, M., Grethe, H., & Zhu, T. (2020). Climate change and agriculture in the Sudan: Impact pathways beyond changes in mean rainfall and temperature. *Ecological Economics*, *169*, 106566. https://doi.org/10.1016/j.ecolecon.2019.106566

Verner, D., & Breisinger, C. (2013). *Economics of climate change in the Arab world: case studies from the Syrian Arab Republic, Tunisia and the Republic of Yemen*. World Bank Publications.

World Bank. (2015). Sudan Country Economic Memorandum: Realizing the Potential for Diversified Development. Washington, DC: World Bank.

Bridging the Energy Gap for Digital Agriculture: Challenges and Solutions for AI and Robotics Adoption in Sub-Saharan Africa's Smallholder Farms

Oluwadare Adebisi [1], Yusuff Adebonuola Lawal [2], Samson Oladayo Ayanlade[3]

[1]Electrical and Electronics Engineering, College of Agriculture, Engineering and Sciences (COAES), Bowen University, Osun State, Nigeria. Email: adebisioluwadare@gmail.com ORCID: 0000-0001-7009-563X

[2]Mechanical and Mechatronics Engineering, Faculty of Engineering and Technology, Abiola Ajimobi Technical University, Ibadan, Nigeria. Email: yusuff.lawal@tech-u.edu.ng.

[3]Electrical and Electronics Engineering, College of Engineering and Environmental Sciences, Olabisi Onabanjo University, Ago-Iwoye, Nigeria. Email: ayanlade.oladayo@oouagoiwoye.com

Abstract

Smallholder agriculture in Sub-Saharan Africa faces many obstacles, such as unstable energy sources, poor infrastructure, and restricted access to cutting-edge technologies. Despite these challenges, smallholder farms play a crucial role in food security and poverty alleviation. Agricultural productivity and resilience to climate change could be improved by the use of cutting-edge technologies. However, the absence of reliable and affordable energy makes it difficult to integrate these technologies in rural areas. This study examines the energy requirements of Artificial intelligence, robotics, and drones in smallholder farming. It assesses the feasibility of solar, wind, and biomass energy as substitutes for conventional grid power. Through field surveys, semi-structured interviews, and case studies from Kenya, Nigeria, and Tanzania, the study identifies the gaps in energy infrastructure. Practical solutions to bridge the gaps are also suggested. This research provides a roadmap for policymakers, energy suppliers, and agricultural stakeholders to foster an energy-secure future for smallholder farmers in Sub-Saharan Africa.

Keywords: Artificial Intelligence, Energy access, Smallholder farming, Agricultural robotics, Solar energy

Introduction

Sub-Saharan Africa relies on smallholder agriculture for food, providing for over 60% of the region's population (Sakho-Jimbira, & Hathie, 2020). Most of these farmers, managing less than two hectares of land, often face numerous challenges due to their limited access to advanced technologies, financial struggles, the impacts of climate change, and inadequate infrastructure. Nevertheless, smallholders play a crucial role in ensuring food security, alleviating poverty, and promoting development in rural areas across Africa (Kapari *et al.,* 2023). Implementing advanced technologies in agriculture is essential for overcoming these challenges and increasing the region's food production.

Artificial Intelligence, robotics, and drone technologies have recently started to significantly transform farming worldwide, making it more efficient, precise, and sustainable (Dayıoğlu *et al.,* 2021). By utilizing AI, farmers can collect and analyze vast amounts of data to inform decisions regarding planting, pest management, and crop monitoring. With the aid of robotics and drones, tasks such as harvesting, weeding, and crop irrigation are increasingly automated, providing valuable insights and creating maps of the fields.

These advanced tools can enhance productivity for smallholder farmers in Sub-Saharan Africa, reduce farming expenses, and improve resilience to climate change through more efficient resource use. However, implementing these sophisticated systems in remote areas is challenging due to issues such as limited energy access, inadequate infrastructure, and high costs associated with installation and maintenance.

This paper examines the energy requirements and sustainable methods for integrating AI, robotics, and drones into smallholder farming in Sub-Saharan Africa. The effectiveness of these technologies heavily relies on the availability of sustainable, affordable, and reliable energy sources. Many rural regions in Sub-Saharan Africa are not connected to electric grids, complicating the integration of new agricultural machinery. Consequently, this limitation hinders the full utilization of AI, robotics, and drones in these agricultural fields.

Literature Review

The Use of AI, Robotics, and Drones in Smallholder Agriculture

AI, robotics, and drones have been extensively discussed in smallholder agriculture recently due to their potential to transform farming and help farmers work more efficiently (Patel *et al.,* 2025). Implementing these technologies enhances crop management, improves precision farming, and accelerates labor-intensive tasks (Charania & Li, 2020*,* 2018; Taha *et al.,* 2025; Sharma & Shivandu, 2024; Karunathilake *et al.,* 2023). Farmers in Sub-Saharan Africa have increasingly begun utilizing AI-based tools for monitoring crops and detecting diseases (Mahenge *et al.,* 2023; Reiger, 2022; Songol *et al.,* 2021). By analyzing satellite and drone images, AI algorithms provide real-time insights about crops, soil, and environmental factors that affect their yield (Goswami & Nayak, 2022; Padhiary *et al.,* 2024).

Agricultural work that requires significant physical effort is being simplified with the use of robotics and automation (Marinoudi *et al.,* 2019; Oliveira *et al.,* 2021). For instance, in numerous locations, autonomous robots are being utilized to plant seeds, measure soil moisture, and harvest crops (Oliveira *et al.,* 2021). Sub-Saharan Africa views robots as promising, particularly in regions where hiring enough workers is both difficult and expensive, such as during harvesting (Gaus & Hoxtell, 2019). Utilizing robots could replace some human labor, increase efficiency, and enable smallholders to address labor shortages (Rai *et al.,* 2023).

Precision agriculture has effectively utilized drones to survey fields from above, irrigate plants accurately, and apply fertilizers and pesticides in a controlled manner (Guebsi *et al.,* 2024). Farmers can leverage drones to capture clear images and identify areas of land that need attention, helping them distribute resources more efficiently (McCarthy *et al.,* 2023). Smallholder farms in Sub-Saharan Africa, often isolated, find drones to be a promising tool for gathering data and informing decisions (Choruma *et al.,* 2024).

The Energy Requirements of AI, Robotics, and Drones in Agriculture

Adopting AI, robotics, and drones across farms causes a surge in energy demands, which can be hard to manage in areas where the power infrastructure is unreliable (Ghobadpour *et al.,* 2022; Chinonyerem *et al.,* 2025). Using AI for processing information and making choices demands lots of computing resources (Hossain *et al.,* 2023). The high energy needs of advanced farming technology may stop many smallholder farmers from using it. For example, the energy used for machine learning algorithms in AI-based crop monitoring systems may be high, particularly if data is processed in real-time or over large areas (Akintuyi, 2024; Kowalska & Ashraf, 2023).

Tasks such as harvesting, irrigation, and weeding are handled by robotics that often depend on the use of batteries and electric motors. The amount of energy these robots use varies with their size, level of complexity, and the number of operational hours. Robotics in areas far from electricity supplies encounter significant challenges when it comes to a steady power source (Hassan *et al.,* 2020; Iqbal *et al.,* 2019). Furthermore, it can be both costly and challenging to set up the charging stations needed to operate autonomous robots in farms in remote places (Ghobadpour *et al.,* 2022).

The batteries powering drones need to be strong enough to operate them during long drone flights and in areas far from the nearest electricity source. Drones use energy depending on their operating time, the kinds of sensors involved, and the weight of their payloads (Zhang *et al.,* 2021). The fact that many smallholder farmers in Sub-Saharan Africa do not have continuous electricity makes it harder to use drones widely.

Sustainable Ways of Powering Agricultural Technologies

As energy supply is difficult in Sub-Saharan Africa's rural areas, sustainable solutions must be found to support AI, robotics, and drones in smallholder farming. Off-grid areas in agriculture now depend on solar energy because it is one of the leading renewable power sources available (Mantri *et al.,* 2020; Rahman *et al.,* 2022). Solar systems for irrigation have become common in rural Africa, giving farmers an opportunity to use water without relying on the grid for power (Wazed *et al.,* 2018). Drones and robots can be charged through solar energy, so it is a good alternative for farmers who do not use the grid.

Wind energy and biomass are being considered as options for energy in the agriculture sector. Rural communities in some regions of Sub-Saharan Africa have been given energy from wind turbines (Yimen *et al.,* 2018; Babayomi *et al.,* 2023). Agricultural waste can be used to produce biomass energy, which is under study as a sustainable method for powering farming activities (Saleem *et al.,* 2022). Some places have installed small biomass plants to turn agricultural wastes into power, which is then sent to robots, drones, and AI systems.

It has been noticed that mixing solar, wind, and battery power can provide steady and dependable energy for farming families (Majeed *et al.,* 2023; Rahman *et al.,* 2022). They maintain a balanced supply by keeping extra power created during the day for use when solar or wind energy is unavailable at night (Lehtola & Zahedi, 2019; Rahman *et al.,* 2022). These systems are helpful in remote areas that do not have a reliable source of national energy, making sure important tools remain functional for farmers.

Energy Infrastructure and Problems Faced in Sub-Saharan Africa

There are major issues with energy infrastructure in Sub-Saharan Africa, mainly affecting rural regions. The International Energy Agency (IEA) states that, in Sub-Saharan Africa, nearly 600 million people have no electricity, and many smallholder farmers turn to firewood and charcoal for their energy supply (IEA, 2019). Because of limited energy, AI, robotics, and drones have a limited role in agriculture (Obeng-Ofori). Also, it is difficult to implement modern energy solutions in rural regions because they are costly to build.

Areas that have electricity often experience a lot of power outages and instability. The unpredictable nature of the grid may cause AI, robotics, and drone systems to work ineffectively. For that reason, the problem is ensuring not just access to energy but also reliable and stable energy so that new technology can be brought into farming (Majeed *et al.,* 2023; Rahman et al., 2022).

Using AI, robotics, and drones in smallholder farming in Sub-Saharan Africa could change the field, leading to better productivity, fewer resources being used, and more jobs being done with less labor. However, the achievement of these technologies is connected to getting enough energy that is both available and sustainable. Using solar, wind, and biomass energy might provide enough power for these technologies, although they still deal with problems such as expensive infrastructure, high costs, and restricted access. To use all the benefits AI and robotics offer smallholder farmers, we should focus on powering these technologies with sustainable energy and making sure suitable infrastructure is in place.

Studies on adopting agri-technology and providing rural energy are increasing in SSA, but relatively few have looked directly at how these two issues connect. In more detail, research has not fully addressed how AI tools impact the energy required, as well as the effects of energy infrastructures on AI implementation. The study helps narrow the gap by carefully analyzing what smallholders need and what energy is supplied, always keeping their inclusion and sustainable practices in mind.

Methodology

The researchers analyzed the case of smallholder farmers in Kenya, Nigeria, and Tanzania, where the sites were selected due to their varying rates of technology use and energy access. Field surveys engaged 68 farmers, and 12 key informants (developers of agri-tech and local energy suppliers, as well as policy officers) were interviewed. The questionnaires fetched information regarding the energy consumption, mode of access (e.g., solar, diesel), as well as the availability of smart farming tools. Interviews examined obstacles to adoption, attitudes toward energy solutions, and institutional-level coordination. A more detailed analysis was carried out on three case study farms (one per country) based on their utilization of either AI or robotic equipment, energy system (e.g., solar or hybrid), and crop type.

Research Design

This study employed a mixed-methods design that involved collecting data using both qualitative and quantitative approaches. With this methodology, we were able to analyze the energy consumption of AI, robotics, and drones while also understanding the circumstances of smallholder farmers regarding energy accessibility and the adoption of new technologies. The study gathered vital information through field surveys, semi-structured interviews, and case studies, supported by data from existing research.

Data Collection Methods

Field Surveys

Quantitative field surveys were done to gather information on how much energy is used by AI systems, robotic tools, and drones in smallholder agriculture. The survey instrument was made to obtain information about the following areas:

1.AI, robotic, and drone technologies that are currently being used on smallholder farms

2.Energy usage behaviors for the diverse technologies

3.The types of energy used on farms (e.g., solar, electricity from the grid, and off-the-grid renewables)

4.The number of times energy failures or shortages happen

5Expenses related to the use of energy in agriculture

Those included in the study were smallholder farmers who had already picked up or were interested in adopting these technologies.

Semi-Structured Interviews

Key individuals from both the agricultural and energy sectors were interviewed extensively using a semi-structured approach. This group included smallholder farmers, companies that develop agricultural technology, energy suppliers, and decision-makers involved in rural electrification projects. The interviews were designed to gather insights:

1.The challenges people face in getting energy and their role in adopting AI, robotics, and drones

2.Renewable energy sources, including solar and wind, have both benefits and disadvantages in powering agricultural technologies

3.Obstacles that prevent rural areas from adopting these innovations.

4.Ways to boost energy access and assist smallholder farmers in using these technologies.

Case Studies

So, to study the effects of increased energy use and new technologies, we examined how AI, robotics, or drones were used on successful smallholder farms. Looking at case studies made it possible to track energy use and measure how well these systems operate in rural areas. Various farm sizes, crop types, and energy sources were observed for these case studies, with attention on those that rely on solar power and other eco-friendly methods.

We went to the sites to watch the technologies being used, determine their electricity use, and record the energy systems installed at the buildings (including solar panels, wind turbines, and battery systems). Talking with farm operators and workers gave meaning to the technical information we collected. The case studies explained the particular energy demands of AI-based systems, robots, and drones used in agriculture.

Data Analysis

Quantitative Data Analysis

The information from the field surveys was processed statistically to find energy usage trends and look for relationships between energy access and technology. The statistics were employed to provide an overview of the amount of energy used by AI, robotics, and drone systems. SPSS and R were applied to analyze quantitative data. Descriptive statistics (mean, variance) were applied to summarize energy consumption by the technology type. Then, the linear regression models were used to analyze the connection between the farm size and the energy demand, where the independent variables were the type of technology, the source of energy on the farm, and the hours of operation. The significance was checked with the help of p-values (the cut-off point: 0.05) and R^2 values that show the strength of explanatory variables. Thematic coding and categorization of qualitative data with the help of NVivo software made it possible to compare emerging issues across cases (affordability, trust, and infrastructure reliability).

Qualitative Data Analysis

Information from the semi-structured interviews and case studies was analyzed via a thematic analysis process. The interview transcripts and case study notes were coded to highlight significant subjects about energy access, agricultural technology use, and limits to adoption. With thematic analysis, it was possible to notice repeated findings and better understand what influences the integration of AI, robotics, and drones in smallholder agriculture.

It allowed for a greater insight into farmers' beliefs about energy availability, whether renewable energy works, and the obstacles to using these new technologies in rural regions. NVivo software was used to help arrange and analyze the qualitative data gathered.

Assessing Sustainable Energy Solutions

An assessment was made during the study to test how renewable energy supports new technologies used in agriculture. Solar, wind, and biomass technologies were seen as suitable methods for farming communities that are not connected to a grid in Sub-Saharan Africa (Babayomi *et al.,* 2023). Some of the case studies featured farms operated with solar-driven irrigation, drone and robot charging areas, and bioenergy plants on a small scale. It checked if the approaches were reasonable, cost-effective, and adaptable in different circumstances, while considering local energy sources, farm area, and existing technical equipment.

Ethical Considerations

The study stuck to ethical standards for gathering and studying data. Each person who took part in the surveys and interviews gave consent and their privacies were protected by withholding their identities. Ethics was a priority in the study and it protected the well-being of those who took part in the research in rural areas. The research was approved ethically by the required review boards before it was conducted.

Limitations

The study has some important weaknesses, even though it examines a broad range of factors. The research was limited to three regions of Sub-Saharan Africa (Kenya, Nigeria, and Tanzania), so its results may not reflect the entire region. There were also difficulties in obtaining data on energy use for AI and robots in places where technology adoption was still in its early stages. Although, the study explains how much energy is needed by these technologies, the differences in energy infrastructure across regions make it difficult to analyze all aspects.

Results and Discussion

The Energy Requirements of AI and Robotic Equipment

Figure 1 shows the projected daily energy use of some standard AI-based farm technologies for smallholders. In terms of average daily energy use, autopilot field robots for spraying or weeding need the most at 1.2 kWh each day. Such robots need to operate for a long time and must be charged many times, which leads to a high energy demand.

Drones used in agriculture for mapping and spraying need nearly 0.25 kWh of electricity per day, most of which is used during charging periods between flights. Drones, unlike robots, are not as energy demanding, but they still require steady electricity when agriculture is at its busiest.

At the lower end of the scale are edge AI cameras (0.18 kWh/day), IoT base stations (0.10 kWh/day), and soil moisture sensors (0.03 kWh/day). While the systems are not very powerful when one is used, when they are connected in large networks, their combined strength can use more energy.

This means that, even with simple AI and IoT devices, a reliable energy supply is vital for them to work properly, and such conditions are rare in rural African communities.

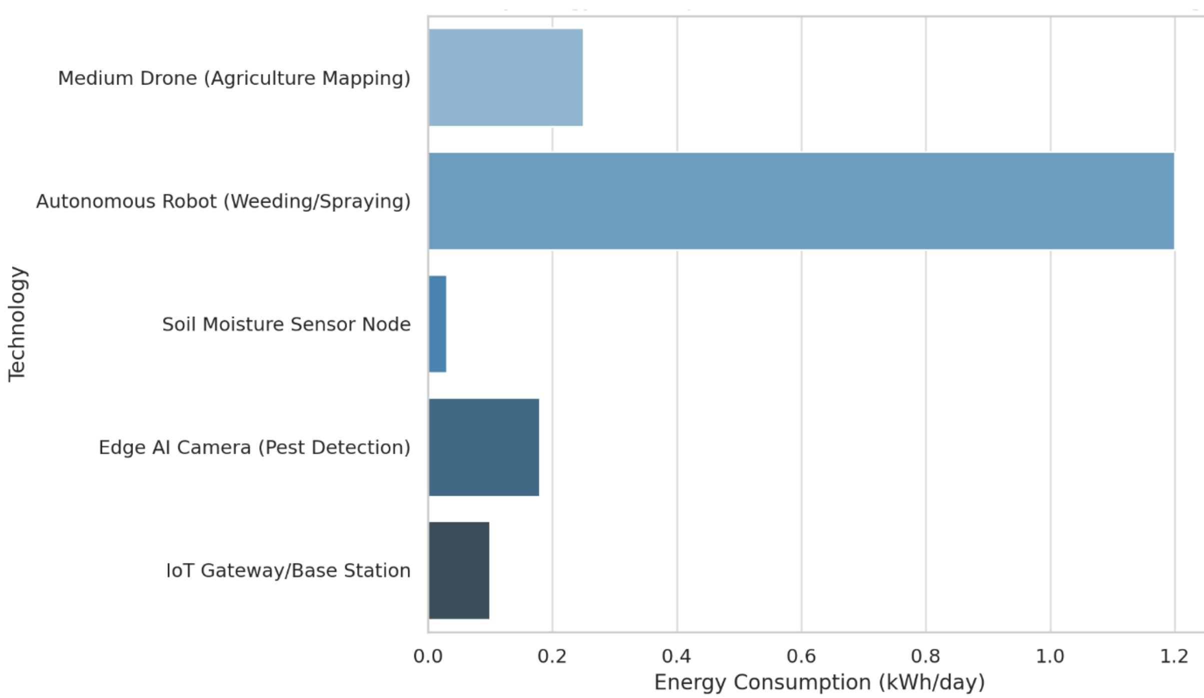


Figure 1: Estimated Daily Energy Consumption of Common AI and Robotic Devices in Smallholder Agriculture.

Energy Access Gaps in Rural Sub-Saharan Africa

Although the role of digital agriculture is being recognized more, this field is still hindered by energy issues in most small-scale farms in Sub-Saharan Africa. Based on research from the International Energy Agency (IEA, 2022), only 20% of rural areas in Chad, Malawi, and the Democratic Republic of Congo have access to electricity, and in the region as a whole, 55% of families are not connected to the grid. Rural electrification is often unstable and unreliable, even in well-developed economies such as Nigeria and Kenya, especially around farms.

Grid electricity is often not dependable, is easily disrupted by outages, and doesn't reach much of the farming areas. As a result, deploying energy-dependent devices like drones, robotic weeders, or sensor networks becomes more difficult since they must be charged often, and the power must be reliable. Therefore, some farmers depend on diesel generators, which are not eco-friendly and costly to run, especially for smallholder farmers who cannot afford much.

Many smallholders are still unable to set up off-grid systems because they are too expensive; however, if subsidized or managed by communities, they can be more accessible. Support for these systems is not always what it should be, which makes them less useful as time goes on. A lack of a unified approach between the agriculture and energy development sectors has led to most rural electrification strategies missing the special power needs of current agricultural technology.

The obstacles in energy access greatly hamper the potential of AI and robotics to narrow the working productivity gap among smallholders. Failure to address these concerns could leave a wider gap in benefits for farm communities using technology compared to those lacking access, and protect existing challenges to innovation and food safety in rural areas.

Feasible Energy Solutions for Smallholder AI Integration

To handle the increased energy needs of AI and robotics in smallholder farming, various off-grid and renewable projects have been tried out across Sub-Saharan Africa. The level of feasibility for each system is affected by how much it costs, how large it can be, and whether it fits with the technologies used in farming.

A standalone solar photovoltaic (PV) system is a promising choice because it supplies clean power to farms in remote areas. You can run drones, charging stations, environmental sensors, and edge AI cameras using these systems. Solar-powered solar farms in Kenya, such as those by SunCulture and PowerGen, make it possible to conduct basic irrigation and use mobile devices through sensors, boosting farming production without using much fuel.

A flexible power source for drone and remote robot tasks comes from portable solar battery kits. Equipped with these kits, farmers do not have to depend on a fixed energy source to charge farm equipment while working in the fields. High initial costs are balanced by lower long-term expenses for fuel and grid extension, so cooperative groups can make them work.

Having mini-grids with diesel and solar energy systems is an additional solution that is suitable for clustered farming communities. These systems can support central processing, keep products well-stored, and coordinate various robotic services used together (such as widespread spraying by robots). However, to put these systems into practice, it is necessary to fund them and work together with local authorities, developers, and energy regulators.

Low-power AI chips and energy-efficient edge computing are becoming more popular in technological advances. The NVIDIA Jetson Nano or Google Coral devices with microcontrollers make it possible to analyze data from farms at the site with less energy needed. It helps decrease energy use from cloud solutions and supports instant reactions to situations on the ground with little infrastructure.

Every community has its own set of problems, so no one method can be used everywhere. A suitable energy strategy should take into account the energy technology, the size of the farm, the local energy environment, and how much farmers can afford. Offering training, a fair cooperative structure, and encouraging policies might be the most effective way to use these energy systems for AI use in small farms.

Comparing Energy Alternatives

Figures 2, 3, and 4 present a comparison of different energy sources that could power AI and robotic tools used in Sub-Saharan African smallholder farming. The system is assessed through grid electricity, diesel generators, standalone solar photovoltaic (PV), solar with batteries, and hybrid mini-grids.

From Figure 2, it can be seen that standalone solar PV systems and hybrid mini-grids have the greatest initial cost at $1,200 and $5,000, respectively. On the other hand, diesel generators and grid electricity cost less at the start, which is why they are more attractive for quick use. On the other hand, using these methods comes with lasting downsides.

Figure 3 displays that diesel generators have a low purchase price but require the most monthly expenses, which add up to $70, due to the amount of fuel they use and the upkeep. Solar + battery solutions and solar PV installations work out to be much lower in operating costs (around $5–$10 a month) and are the most cost-effective over time when linked to small-power tools like sensor arrays and drone charging.

Results in Figure 4 demonstrate the way energy options rank in terms of reliability and sustainability from worst (1) to best (10). Hybrid solar mini-grids and solar-based systems are rated the best, scoring 8–10 for both sustainability and reliability since they can last well and are less likely to fail. Though diesel generators are usually reliable (score of 8), they have a low sustainability rating (2) because of environmental problems caused by their emissions and reliance on gas prices that can easily fluctuate.

According to the findings, while renewables may require a bigger upfront investment, they ensure stronger and more sustainable energy solutions, mainly when used as part of decentralized or group projects. The choice between initial outlay and long-term efficiency in using energy must be given extra attention in designing energy strategies for agriculture.

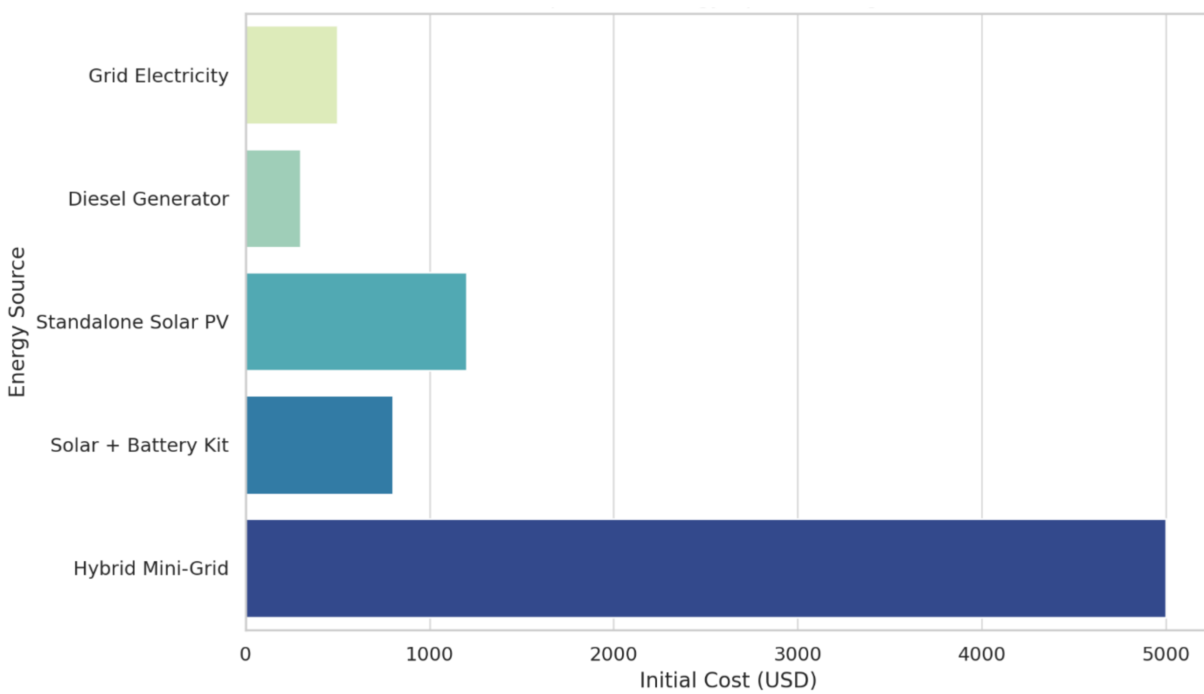


Figure 2: Initial Setup Cost of Energy Options for Agri-Tech in SSA

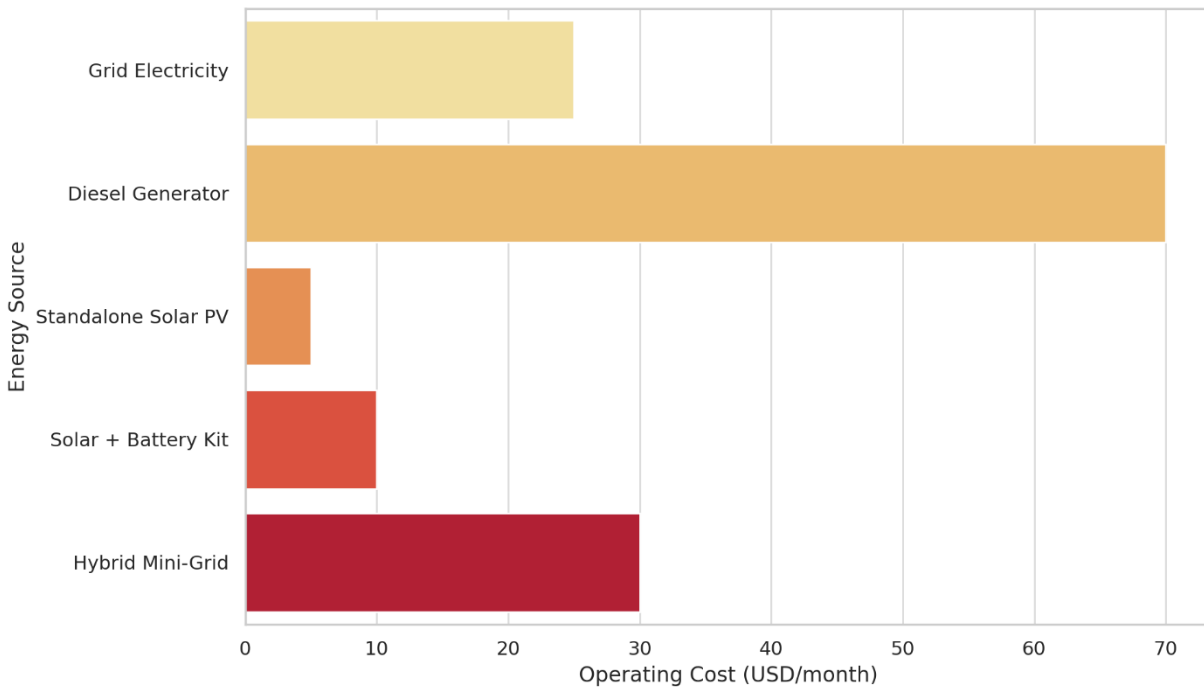


Figure 3: Monthly Operating Cost of Energy Options

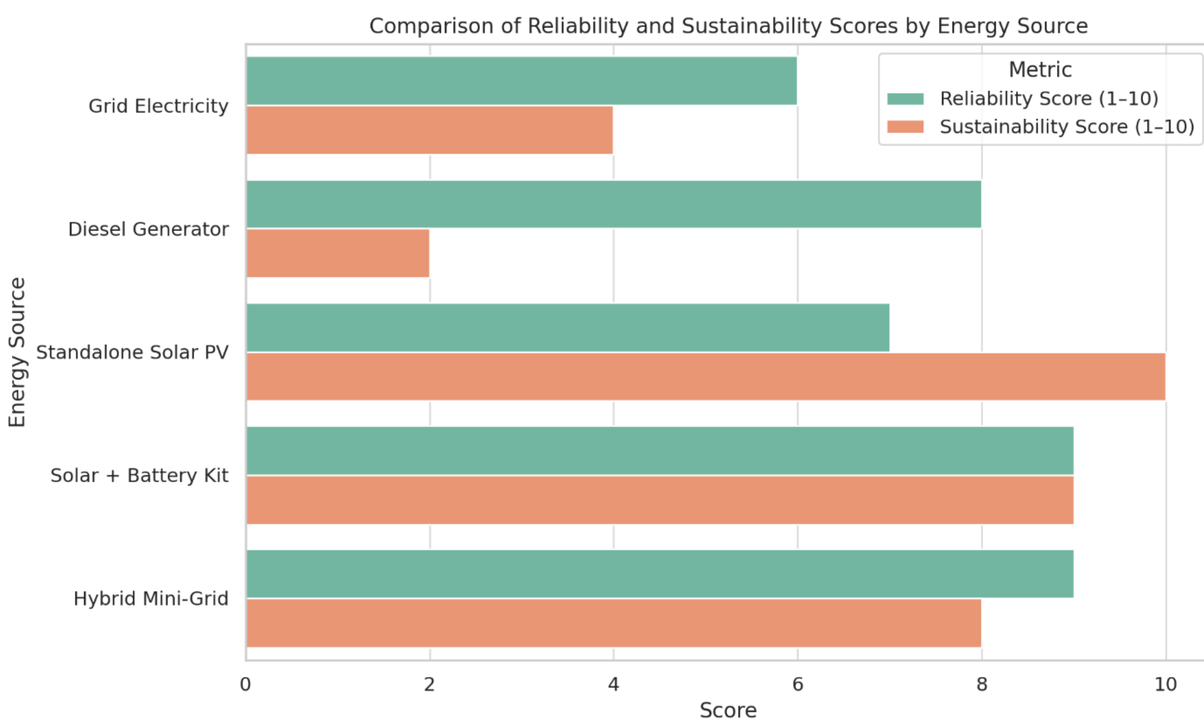


Figure 4: Comparison of Reliability and Sustainability Scores by Energy Source

Problems with Integrating AI and Robotics into Smallholder Agriculture

AI's use and adoption of robotic technologies in Sub-Saharan African agriculture remain limited due to several overlapping obstacles. These challenges extend beyond technology, encompassing structural, financial, institutional, and cultural issues.

High costs significantly hinder the acquisition and integration of AI and robots. Most smallholder farmers operate on very tight budgets, with limited access to official credit or investments. Even with the availability of energy-efficient solutions, initial investments and necessary supporting equipment, such as solar panels, batteries, and connectivity tools, are often out of reach for many individuals without external support.

Additionally, limited training and technical expertise are closely tied to the financial challenges. Low digital literacy and insufficient technical knowledge make it difficult for numerous rural communities to effectively use drones, autonomous robots, and smart sensors. In many areas, when local experts or suppliers are unavailable, these technologies tend to be abandoned after initial pilot deployments. Language differences and low levels of education further complicate the adoption of the Internet among these populations.

There is also a significant issue with policies and support systems being fragmented or disconnected. Many agricultural development strategies in Sub-Saharan Africa do not adequately incorporate energy or digital technology planning. Simultaneously, these programs often fail to address the needs of users reliant on agriculture and technology. This gap results in challenges in finding coherent frameworks, sufficient financial support, and effective connections between the public and private sectors in these areas. Without coordinated efforts, the use of AI and robotics in modernizing agriculture may occur in isolation, risking failure to achieve widespread adoption.

Problems with culture and trust are also factors to consider. In many farming communities, people tend to stick to traditional methods and might regard new technologies with doubt or dislike. If plans are not made with and adapted to the needs of the community, their acceptance may be only on the surface or used mostly for show.

Lack of proper roads, reliable phone networks, and sometimes interrupted internet connections make things worse for the population. These conditions make it hard to build the necessary energy infrastructure for AI use and to manage remote monitoring and data sharing in modern agriculture.

Handling these issues will need to include all sectors and bring together governments, research groups, energy suppliers, developers in agri-tech, and members of local communities. The positive changes AI and robotics can bring to smallholder agriculture in Africa will not become a reality unless intentional actions are taken.

Policy Recommendations

This research highlights the importance of implementing policies that balance technology and infrastructure to assist small farmers in Sub-Saharan Africa. Energy must be recognized as a key factor in planning AI and robotics applications in agriculture. The recommendations outlined below are proposed:

Integrate Agricultural and Energy Planning.

Policymakers should unite the ministries of agriculture, energy, and technology to formulate cohesive plans that promote the development of digital agriculture. Upgrading rural energy systems should be a primary goal in any national agricultural modernization plan, and rural electricity programs must be prepared for the new energy demands of precision farming technologies.

Expand Access to Off-Grid Renewable Energy Systems.

Governments and development partners should allocate funds toward solar standalone systems, mobile battery kits, and mini-grids designed for agriculture. Subsidies should be provided for smallholder use, and these systems can also be rented through PAYG or cooperative methods. Supporting youth and women in agriculture is crucial, as they often receive inadequate attention in energy access initiatives.

Support Innovation in Low-Power Agricultural Technologies

Developers of agricultural technologies should be encouraged to create AI and robotics tools that consume minimal energy and can operate in remote areas. Innovative research through public-private partnerships and research grants should focus on advancing AI computing, solar-powered robotics, and adaptive sensor networks to minimize energy consumption as much as possible.

Enhance Community Technical Expertise

Authorities, educational institutions, and NGOs should collaborate to establish and support training and technology centers that teach the use, maintenance, and repair of agri-digital machinery and their energy systems. Both the substance and language of training should be adapted to the local culture to encourage longer and more effective usage.

Create Incentives for Digitally Sustainable Farming

Governments should contemplate supportive policies, such as waiving taxes, implementing lower or no import tariffs, and offering affordable loans for farmers transitioning to clean energy. Engaging local energy service providers in the agricultural sector may lead to the emergence of new businesses and a more sustainable future.

Strengthen the Establishment of Community-Based Energy Cooperatives

In certain instances, community management of energy has proved beneficial in various sectors and could also enhance agriculture. Establishing solar stations for drones or providing AI processing centers for drone collectives can help reduce costs and make drone technology accessible and collaborative.

Conclusion

Using robotics and artificial intelligence in smallholder agriculture holds great promise for overcoming challenges like labor shortages, maintaining steady productivity, and adapting to climate change. However, this research highlights that energy scarcity is a critical issue often overlooked in efforts to transform Sub-Saharan Africa's agriculture. After analyzing the energy demands of agri-tech devices and evaluating rural energy supplies, the study reveals a stark gap between AI's potential and the current support available at smallholder farms.

The results suggest that decentralized solar power, along with simpler sensor arrays and edge devices, can be effective. Nonetheless, energy-intensive tools such as drones and autonomous robots need power sources that are reliable, scalable, and affordable. Many off-grid farming regions lack dependable electricity, technological support, or policies to smoothly integrate energy and farming.

To address these issues, the study proposes practical solutions like standalone solar gadgets, mini-grids, and mobile battery systems tailored to community needs. The importance of sustainability and inclusivity is stressed by advocating for better energy infrastructure and fair financial strategies to ensure successful implementation. Without these policies, digital farming initiatives risk widening the gap in rural technological access, leaving energy-poor areas even further behind.

This research helps evaluate energy limitations in digital agriculture but does not incorporate real-time field data. Future research should include field trials, benefit-cost analyses, and user experience studies at various sites to ensure findings are applicable across different ecological zones.

Acknowledgements

The authors gratefully seize the opportunity to express their appreciation for the invaluable help they received during this research process. Special thanks are extended to the smallholder farmers, agri-tech developers, and energy service providers in Kenya, Nigeria, and Tanzania who generously shared their time, knowledge, and experience. They played a crucial role in the success of the fieldwork and case studies.

With deep gratitude, the academic supervisors and faculty members whose advice and comments helped shape the course of the current study are acknowledged. Appreciation is also directed to the data analysts and technical reviewers who assisted throughout the data interpretation process.

The author also credits the numerous open-access websites, institutional databases, and journals that provided access to several crucial pieces of literature and instruments.

References

Akintuyi, O. B. (2024). Adaptive AI in precision agriculture: a review: investigating the use of self-learning algorithms in optimizing farm operations based on real-time data. Research Journal of Multidisciplinary Studies, 7(02), 016-030.

Babayomi, O. O., Olubayo, B., Denwigwe, I. H., Somefun, T. E., Adedoja, O. S., Somefun, C. T., ... & Attah, A. (2023). A review of renewable off-grid mini-grids in Sub-Saharan Africa. Frontiers in energy research, 10, 1089025.

Charania, I., & Li, X. (2020). Smart farming: Agriculture's shift from a labor intensive to technology native industry. Internet of Things, 9, 100142.

Chinonyerem, C. A., Dennis, E. C., Catherine, O. C., Temiloluwa, O. E., & Jumbo, U. I. (2025). Synergizing robotics and artificial intelligence for optimized renewable energy maintenance: a focus on wind and solar power. International journal of applied and advanced engineering research.

Choruma, D. J., Dirwai, T. L., Mutenje, M., Mustafa, M., Chimonyo, V. G. P., Jacobs-Mata, I., & Mabhaudhi, T. (2024). Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in sub-saharan africa. Journal of agriculture and food research, 101286.

Dayıoğlu, M. A., & Turker, U. (2021). Digital transformation for sustainable future-agriculture 4.0: A review. Journal of Agricultural Sciences, 27(4), 373-399.

Gaus, A., & Hoxtell, W. (2019). Automation and the future of work in Sub-Saharan Africa. Berlin: Konrad Adenauer Stiftung.

Ghobadpour, A., Monsalve, G., Cardenas, A., & Mousazadeh, H. (2022). Off-road electric vehicles and autonomous robots in agricultural sector: trends, challenges, and opportunities. Vehicles, 4(3), 843-864.

Goswami, B., & Nayak, P. (2022). Optimization in agricultural growth using AI and satellite imagery. In Data Science in Societal Applications: Concepts and Implications (pp. 107-125). Singapore: Springer Nature Singapore.

Guebsi, R., Mami, S., & Chokmani, K. (2024). Drones in precision agriculture: A comprehensive review of applications, technologies, and challenges. Drones, 8(11), 686.

Hassan, A. A., El Habrouk, M., & Deghedie, S. (2020). Renewable Energy for Robots and Robots for Renewable Energy–A Review. Robotica, 38(9), 1576-1604.

Hossain, M. E., Tarafder, M. T. R., Ahmed, N., Al Noman, A., Sarkar, M. I., & Hossain, Z. (2023). Integrating AI with Edge Computing and Cloud Services for Real-Time Data Processing and Decision Making. International Journal of Multidisciplinary Sciences and Arts, 2(4), 252-261.

Iqbal, J., Al-Zahrani, A., Alharbi, S. A., & Hashmi, A. (2019). Robotics inspired renewable energy developments: prospective opportunities and challenges. IEEE Access, 7, 174898-174923.

Kapari, M., Hlophe-Ginindza, S., Nhamo, L., & Mpandeli, S. (2023). Contribution of smallholder farmers to food security and opportunities for resilient farming systems. Frontiers in Sustainable Food Systems, 7, 1149854.

Karunathilake, E. M. B. M., Le, A. T., Heo, S., Chung, Y. S., & Mansoor, S. (2023). The path to smart farming: Innovations and opportunities in precision agriculture. Agriculture, 13(8), 1593.

Kowalska, A., & Ashraf, H. (2023). Advances in deep learning algorithms for agricultural monitoring and management. Applied Research in Artificial Intelligence and Cloud Computing, 6(1), 68-88.

Lehtola, T., & Zahedi, A. (2019). Solar energy and wind power supply supported by storage technology: A review. Sustainable Energy Technologies and Assessments, 35, 25-31.

Mahenge, M. P. J., Mkwazu, H., Sanga, C. A., Madege, R. R., Mwaipopo, B., & Maro, C. (2023). Artificial intelligence and deep learning based technologies for emerging disease recognition and pest prediction in beans (phaseolus vulgaris l.): A systematic review. African Journal of Agricultural Research, 19(3), 260-271.

Majeed, Y., Khan, M. U., Waseem, M., Zahid, U., Mahmood, F., Majeed, F., ... & Raza, A. (2023). Renewable energy as an alternative source for energy management in agriculture. Energy Reports, 10, 344-359.

Mantri, S. R., Kasibhatla, R. S., & Chennapragada, V. K. B. (2024). Grid-connected vs. off-grid solar water pumping systems for agriculture in India: a comparative study. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 46(1), 6348-6362.

Marinoudi, V., Sørensen, C. G., Pearson, S., & Bochtis, D. (2019). Robotics and labour in agriculture. A context consideration. Biosystems Engineering, 184, 111-121.

McCarthy, C., Nyoni, Y., Kachamba, D. J., Banda, L. B., Moyo, B., Chisambi, C., ... & Hoshino, B. (2023). Can drones help smallholder farmers improve agriculture efficiencies and reduce food insecurity in Sub-Saharan Africa? Local perceptions from Malawi. Agriculture, 13(5), 1075.

Oliveira, L. F., Moreira, A. P., & Silva, M. F. (2021). Advances in agriculture robotics: A state-of-the-art review and challenges ahead. Robotics, 10(2), 52.

Padhiary, M., Saha, D., Kumar, R., Sethi, L. N., & Kumar, A. (2024). Enhancing precision agriculture: A comprehensive review of machine learning and AI vision applications in all-terrain vehicle for farm automation. Smart Agricultural Technology, 100483.

Patel, A., Shukla, C., Trivedi, A., Balasaheb, K. S., & Sinha, M. K. (2025). Smart Farming: Utilization of Robotics, Drones, Remote Sensing, GIS, AI, and IoT Tools in Agricultural Operations and Water Management. In Integrated Land and Water Resource Management for Sustainable Agriculture Volume 1 (pp. 127-151). Singapore: Springer Nature Singapore.

Rahman, A., Farrok, O., & Haque, M. M. (2022). Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. Renewable and sustainable energy reviews, 161, 112279.

Rahman, M. M., Khan, I., Field, D. L., Techato, K., & Alameh, K. (2022). Powering agriculture: Present status, future potential, and challenges of renewable energy applications. Renewable Energy, 188, 731-749.

Rai, A. K., Kumar, N., Katiyar, D., Singh, O., Sreekumar, G., & Verma, P. (2023). Unlocking productivity potential: The promising role of agricultural robots in enhancing farming efficiency. Int. J. Plant Soil Sci, 35(18), 624-633.

Reiger, B. (2022). Adoption of Artificial Intelligence Based Technologies in Sub-Saharan African Agriculture (Master's thesis, Universidade NOVA de Lisboa (Portugal)).

Sakho-Jimbira, S., & Hathie, I. (2020). The future of agriculture in Sub-Saharan Africa. Policy brief, 2(3), 18.

Saleem, M. (2022). Possibility of utilizing agriculture biomass as a renewable and sustainable future energy source. Heliyon, 8(2).

Sharma, K., & Shivandu, S. K. (2024). Integrating artificial intelligence and internet of things (IoT) for enhanced crop monitoring and management in precision agriculture. Sensors International, 100292.

Songol, M., Awuor, F., & Maake, B. (2021). Adoption of artificial intelligence in agriculture in the developing nations: a review. Journal of Language, Technology & Entrepreneurship in Africa, 12(2), 208-229.

Taha, M. F., Mao, H., Zhang, Z., Elmasry, G., Awad, M. A., Abdalla, A., ... & Elsherbiny, O. (2025). Emerging technologies for precision crop management towards agriculture 5.0: A comprehensive overview. Agriculture, 15(6), 582.

Wazed, S. M., Hughes, B. R., O'Connor, D., & Calautit, J. K. (2018). A review of sustainable solar irrigation systems for Sub-Saharan Africa. Renewable and Sustainable Energy Reviews, 81, 1206-1225.

Yimen, N., Hamandjoda, O., Meva'a, L., Ndzana, B., & Nganhou, J. (2018). Analyzing of a photovoltaic/wind/biogas/pumped-hydro off-grid hybrid system for rural electrification in Sub-Saharan Africa—Case study of Djoundé in Northern Cameroon. Energies, 11(10), 2644.

Zhang, J., Campbell, J. F., Sweeney II, D. C., & Hupman, A. C. (2021). Energy consumption models for delivery drones: A comparison and assessment. Transportation Research Part D: Transport and Environment, 90, 102668.

Appendix A: Sample of the Survey Questionnaire

Section 1: Demographics

What is your age?

☐ Under 25 ☐ 25–40 ☐ 41–60 ☐ Over 60

What is your gender?

☐ Male ☐ Female ☐ Other

Section 2: Energy Access

3. What is your primary source of energy on the farm?

☐ Grid electricity ☐ Solar ☐ Diesel ☐ Other (specify)

4. How often do you experience power outages?

☐ Never ☐ Rarely ☐ Often ☐ Daily

Section 3: Technology Use

5. Are you currently using any of the following? (Check all that apply)

☐ Drones ☐ Soil sensors ☐ Autonomous tractors ☐ AI-based crop monitors

What is the biggest challenge you face in using these technologies?

☐ Cost ☐ Power supply ☐ Training ☐ Maintenance

Section 4: Willingness to Adopt

7. Would you be willing to adopt solar-based energy systems if subsidized?

☐ Yes ☐ No ☐ Maybe

List of Figures

The Role of Climate-Smart Agriculture (CSA) in Addressing the Challenges of Food Security and Climate Change in Sub-Saharan Africa: A Focus on Nigeria

Yusuff Adebonuola Lawal[1], Oluwadare Adebisi[2], Shukurat Adedamola Wahab[3]

[1]Mechanical and Mechatronics Engineering, Faculty of Engineering and Technology, Abiola Ajimobi Technical University, Ibadan, Nigeria. Email: yusuff.lawal@tech-u.edu.ng.

[2]Electrical and Electronics Engineering, College of Agriculture, Engineering and Sciences (COAES), Bowen University, Osun State, Nigeria.

[3]Agriculture and Civil Engineering, Faculty of Engineering and Technology, Abiola Ajimobi Technical University, Ibadan, Nigeria.

Abstract

Climate change and food insecurity are among the most pressing and interconnected issues in Sub-Saharan Africa. Agriculture, which fosters prosperity in the region and serves as the primary livelihood for rural populations, is highly vulnerable to climatic disruptions such as unpredictable rainfall, droughts, and soil erosion. Climate Smart Agriculture (CSA) has emerged as a strategic approach to address these challenges by implementing strategies that enhance productivity, resilience, and reduce greenhouse gas emissions.

In this study, we explore how CSA could improve food security amid climate stress, using Nigeria as a case study. Through a literature review and policy analysis, the paper summarizes existing information on CSA technologies, their impact on the four pillars of food security availability, access, utilization, and stability, and the systemic barriers to wider adoption. The findings highlight the importance of interventions like drought-resistant crops, conservation agriculture, agroforestry, and digital advisory services in increasing yields, diversifying diets, and improving climate adaptability.

However, scaling up these practices faces challenges such as weak extension systems, limited access to finance, policy fragmentation, and gender disparities. The study advocates for integrated policy measures, inclusive financing models, investments in rural infrastructure, and cross-sectoral planning to mainstream CSA into national development strategies.

This paper provides practical insights and policy-oriented solutions, contributing to the ongoing discussion on sustainable agricultural transformation in Sub-Saharan Africa and offering strategic guidance to position CSA as a key tool for climate adaptation and food security enhancement.

Keywords: Climate Smart Agriculture, food security, climate change, resilience, smallholder farming

Introduction

Agriculture plays a vital role in Nigeria's food security, livelihoods, and economic growth. It accounts for over a quarter of the national GDP and supports nearly 70 percent of the rural workforce (Bello *et al.,* 2024). However, the sector is increasingly vulnerable to the mounting impacts of climate change, such as rising temperatures, irregular rainfall patterns, prolonged droughts, and floods (Prince *et al.,* 2023). These shocks threaten crop yields and livestock welfare, while weakening the resilience of food supply chains, pushing millions toward food insecurity.

Since Nigeria's population is projected to exceed 400 million by 2050, pressure on land, water, and food resources is expected to intensify (Oseghale *et al.,* 2024). At the same time, the largely rain-fed agriculture sector is minimally mechanized and relies on traditional farming methods, making it highly susceptible to climate change. Addressing food security alongside climate change adaptation presents a dual challenge that demands a transformative approach to agricultural development.

Climate Smart Agriculture (CSA) has emerged as a strategy to enhance food security by improving resilience to shocks (adaptation), boosting productivity, and reducing greenhouse gas emissions from crops (mitigation) (Mutengwa *et al.,* 2023). CSA encompasses a wide range of technologies and practices, including conservation agriculture, agroforestry, drought-tolerant crop varieties, and ICT-based advisory services, all tailored to local conditions and needs.

Although CSA is recognized globally and has gained policy support, especially through platforms like FAO and the Global Alliance for Climate-Smart Agriculture, its implementation in Nigeria remains limited and fragmented. Several pilot projects have shown promise, but large-scale adoption is hindered by policy gaps, lack of financing, farmer awareness, and infrastructural challenges.

The paper discusses how Climate Smart Agriculture can help address the challenges of climate change and food security in Nigeria. It aims to (i) examine the potential of implementing CSA as a strategy for promoting agricultural sustainability, (ii) assess their roles in achieving food security, and (iii) identify institutional, financial, and technical barriers to scaling up CSA. The paper offers insights into sustainable agriculture in Sub-Saharan Africa, as well as implications for policy and development programming, using Nigeria as a case study.

Literature Review

Climate Smart Agriculture and its Concept and Framework (CSA)

Climate Smart Agriculture (CSA) is a system-transclusive approach that aims to help agricultural systems sustainably adapt to rising challenges brought about by climate change. CSA was introduced by the Food and Agriculture Organization (FAO) in the year 2010 and aims to accomplish three interconnected outcomes which are; sustainable increase in agricultural productivity and incomes, adaptation and building resilience to climate change, reducing and/or removing greenhouse gas (GHG) emissions where possible (FAO, 2013). These goals can also be described as the three pillars of CSA.

Unlike other conventional agricultural models, which mainly aim at enhancing yield, CSA lays more stress on the long-term sustainability and resilience of its system. It incorporates components of climate adaptation and climate mitigation in arranging its agriculture and in its farming practice, hence very adaptive to economies with a large number of smallholders in climate-sensitive areas such as Sub-Saharan Africa. The CSA framework understands that farming regimes are firmly rooted within local, ecological, economic, and social environments. In this regard, CSA solutions have to be localized to the context and refer to the individual climatic risks of the communities, their resource availability, and institutional capabilities (Makate, 2019).

The problem with CSA is that it is not a single-technology or single-approach technology and practice, but a holistic and more inclusive approach to security that combines a variety of practices. These are conservation agriculture, agroforestry, integrated crop-livestock systems, drought-tolerant crop varieties, efficient irrigation, weather-based advisory systems, and post-harvest storage technologies (Tesfaye et al., 2023; Erezi et al., 2023). Notably, CSA focuses on inclusive development, encourages gender-sensitive strategies, involvement of youth, and participatory planning, so that the interventions are based on the needs of the most vulnerable populations.

The key aspect of CSA is that it emphasizes a systems approach, and this takes into consideration the relationship between the natural ecosystem, human behavior, infrastructure, and policy. Such an integrated outlook is especially pertinent in nations, such as Nigeria, where several stress sources, including land degradation, population increase, conflicts, and unacceptable market access, overlap with climatic forces to limit agricultural productivity. CSA framework promotes multi-layered governance that implies actors on the farm level up to national policy-makers, enhancing innovativeness and scalability (Sarker et al., 2019).

To operationalize CSA, the FAO and the partners have developed several tools that have been adopted in several countries to inform the design of policies, priority investments, and program implementation, including CSA Sourcebook, EX-ACT (Ex-Ante Carbon-balance Tool), and Climate-Smart Agriculture Investment Plan (CSAIP) approach (FAO, 2017; World Bank, 2016).

Although its momentum has been increasing, the use and scaling up of CSA has not been consistent across the world, most notably in low-income countries with weak institutional and financial capacities. Conditions that allow Successful CSA implementation include strong extension systems, availability of finance and inputs, research and innovation, and sector-coordinated policies (Thornton et al., 2018).

Nigeria Agriculture and Climate Change

The agricultural sector, which is controlled by smallholder farmers (over 90 % of food production in Nigeria), is becoming imperiled due to the negative consequences of climate change. The country is located in the West African climate zone, which experiences high climatic variations in the form of unpredictable rainfall patterns, long dry periods, rising temperatures, the spreading of deserts in the north, and frequent floods in the southern states (Ayanlade et al., 2018; Olagunju, 2015). Such climatic extremes not only affect the productivity of agriculture but also alter planting calendars, destroy infrastructure, and worsen food insecurity among the vulnerable populations, especially in rural areas.

The fact that Nigeria relies on rain-fed farming, which claims a substantial area of about 93 percent of farmed land, increases the sensitivity of the sector to weather anomalies (Nigerian Meteorological Agency [NiMet], 2020). Irrigation coverage in the country does not exceed 5%, and thus, the country is not able to absorb rainfall shortages and prolonged droughts (FAO, 2022). Desertification in Nigeria in northern areas (caused by land degradation and loss of vegetation cover) has led to a reduction in arable land and water, and grazing levels of competition (Azare et al., 2015). Conversely, the coastal erosion and floods that are common in Niger Delta have caused loss of crops, and displacement of agrarian communities in the southern states (Elisha & Felix, 2021).

The Intergovernmental Panel on Climate Change (IPCC, 2021) modelled that yields of staples (e.g., maize, sorghum, and cassava) across West Africa have been and will continue to reduce by an estimated 20 percent by 2050 in the absence of any adaptation. This portends grave consequences to a nation that is already reeling under rampant poverty and high population growth. There is also a risk of livestock production where livestock are exposed to heat stress, which leads to a loss in animal health, reproduction, and feed supply (Johnson, 2018). Climatic variations have also enhanced the increase of crop pests and diseases, such as fall armyworm, which impose further threats to food security and prosperity of income (Adunola et al., 2021).

Besides biophysical effects, the socioeconomic vulnerabilities worsen due to climate change; economic vulnerability is experienced most so in smallholder farmers, who have no access to climatic information, agricultural insurance, extension activities, and resilient infrastructures. These restrictions prevent farmers from being able to anticipate, prepare, and recover to climatic shock and thus decrease their adaptive capacity.

As this sector plays a vital role in food security, employment, and rural livelihoods in the country, it is not only a matter of environment but also an economic and developmental interest to establish climate resilience in Nigerian agriculture. Combining climate-smart agriculture, increasing access to early warning, and making climate-resilient infrastructure are potential solutions to minimizing exposure to risk and maintaining productivity amid persistent climatic change disruptions.

Food Security and Its Dimensions

Food security is a multidimensional term, which according to Food and Agriculture Organization (FAO, 2008), is a situation whereby all people at all time are assured of the ability to access adequate, safe and nutritious food to meet their dietary needs as well as food preferences, which enable them to live an active and healthy life. The broadly used definition is based on four pillars, including availability, access, utilization, and stability.

1.Availability is the physical presence of food in sufficient quantities and this is determined by production, distribution and exchange mechanisms.

2.Access is the capability of people and families to share food either economically or physically.

3.The utilization involves proper biological use of food, and involves proper nutrition food, clean water, sanitation, health care.

4.Stability measures the consistency of availability, access, and use over time, and the situation of withstanding shocks e.g. conflict, climatic incidents, or economic crises (FAO, 2012).

Food security is one of the many development issues in Nigeria. Despite its enormous agricultural potential, characterized by a high diversity of agro-ecological zones, a large labour force, and the availability of lands suitable for agricultural activity, Nigeria has failed to improve upon them due to structural inefficiencies and pressures on the environment. The World Food Programme (2023) reported that more than 25 million people in Nigeria (over 29 % of the national population) were likely to experience acute food insecurity between June and August 2023, mostly because of conflict, inflation, and climatic-related shocks.

Particularly, climate change worsens food insecurity by impinging on all four pillars. Unpredictable rainfalls, increased temperatures, as well as floods, decrease availability due to disruption of planting and harvesting seasons, low yields, and destruction of standing food. Food security is interrupted by climate events, destroying the infrastructure or making rural income insufficient, causing food to become too unaffordable or physically inaccessible. The utilization is also disadvantaged by poor environmental health and disease outbreaks triggered by climate change, in places where clean water and health facilities are scarce. Lastly, rising frequency and strenuousness of climatic shocks, including the long spells of drought in the regions of Nigeria and floods on a recurrent basis in the south, weaken the stability of food systems (Akinkuolie et al., 2025; Gana, 2024).

Women, children, and internally displaced persons (IDPs), who are some of the vulnerable groups, are affected more by the limited coping mechanisms. The food insecurity gap is further exacerbated by gender inequality, denial of access to farm lands, as well as social exclusion due to economic reasons (Etim, 2022).

The adoption of Climate Smart Agriculture (CSA) provides a way to fulfill these dimensions concurrently. CSA increases both availability by increasing productivity with better inputs and methods; access through stabilizing incomes and yields; utilization through better nutrition-sensitive practices, and stability by avoiding disruptions from climate change. Nonetheless, CSA has a limited effect on food security unless it is inclusive of wider policies concerning nutrition, social protection, and the sustainable management of natural resources.

CSA in the context of Nigerian Practices and Technologies

The concept of Climate Smart Agriculture (CSA) is increasingly being implemented in Nigeria to address the two-pronged problem of food security and climate change adaptation (Mashi et al., 2022). Several CSA practices and technologies have been presented and piloted in the National agro-ecological zones of Nigeria, as it varies in climatic and soil as well as socio-economic conditions. Such interventions tend to revolve around the improvement of productivity, adaptive capacity strengthening, and environmental sustainability.

Conservation Agriculture (CA)

In some areas, conservation agriculture, including minimum tillage, crop rotation, and residue retention practices, has been encouraged to combat soil erosion and enhance water retention. This method causes minimal disruptions in the structure of the soil; thus, preserving water, increasing soil biodiversity, and minimizing the loss of carbon (Usman et al., 2018). It is especially applicable in the semi-arid north areas of Nigeria, where there is poor rain, often leading to soil erosion. Nevertheless, adoption is still low because it is labor-intensive, it does not use mechanized implements, and people prefer traditional ploughing using cultural practices.

Crop Varieties Tolerant to Droughts

Drought-tolerant varieties of maize, sorghum, and cassava have been developed and disseminated by research institutions like the International Institute of Tropical Agriculture (IITA) and National Agricultural Research Systems (NARS). These crops have been demonstrated to perform better than traditional crops in water-stressed environments, and they have been implicated in reducing yield variability in rain-fed agricultural systems (Ojeilua et al., 2025). However, the availability of such seeds is normally limited by weak distribution networks, price, and poor extension.

Integrated Farming System and Agroforestry

Agroforestry systems, including the intercropping of trees, like Gliricidia or Parkia biglobosa, with food crops, are gaining popularity in the Middle Belt and southern Nigeria (Aghimien et al., 2021). Such systems enhance microclimates, contribute to carbon sequestration, and provide other revenue (fruits, firewood, etc.), making the soil fertile. Integrated crop-livestock systems where livestock manure is utilized to make crops grow, and crop residues are consumed by animals, are also done to maximize the amount of resources utilized.

Small-scale irrigation and Water Harvesting

CSA initiatives have also encouraged rainwater harvesting, drip irrigation, and solar power water pumps in response to more erratic rainfall as a way to enhance both water availability and efficiency of its use. Programs such as the Agricultural Transformation Agenda Support Program (ATASP) or the initiatives of NGOs have assisted in the adoption of the low-cost irrigation technologies in Kaduna, Kano, and Niger states organized by the Federal Government (FMARD, 2020).

Climate Information Services and ICT

Mobile-based applications like AgroMall, Hello Tractor, and Digital Green give weather predictions, current market prices, and climate advisories to farmers. The tools assist in enhancing decision-making on planting dates, the use of inputs, and controlling pests. Nevertheless, the issues that hamper their scalability are digital literacy, language barrier, and the lack of coverage of mobile networks.

Nutrient and Soil Control

Integrated Soil Fertility Management (ISFM), which provides integrated application of organic matter (compost, manure) and site-specific chemical input, has been advocated through interaction with extension agencies. These methods maximize soil productivity through minimizing over-dependence on artificial fertilizers, hence promoting productivity as well as environmental objectives (Singh & Nath, 2020).

Climate-smart animal production

In Northern Nigeria, the pastoralist communities are using better feed strategies, fodder crops, and veterinary services to cut down their GHG emissions produced by livestock and enhance productivity. Even with these benefits, the issue of conflict of land ownership and the right to graze livestock poses a challenge to the uptake of CSA in the livestock sector.

Obstacles to CSA adoption in Nigeria

The adoption and scale-up of the CSA practices in Nigerian agriculture are limited by diverse institutional, economic, social, and technical challenges despite the present opportunities that CSA has to improve resilience, productivity, and sustainability of agricultural enterprises in Nigeria. The effects of these constraints not only make the diffusion of innovations slow but also restrict the transformative capabilities of CSA in meeting the national goals of food security and climate adaptation.

Access to Finance and Inputs Financing Capital

One of the major constraints of smallholder farmers is access to credit and inputs. A major portion of the CSA technologies also comes with an initial investment, which hinders an inability to adopt such technologies by the rural farmers. Nigeria has an underdeveloped agricultural lending environment where the banks lack interest in lending to agriculturists, considering the risks involved, inadequate loan securities, and low insurance (Balana & Oyeyemi, 2022). In places where the government programs are available (e.g. Anchor Borrowers Programme), entry tends to be restricted to the large-scale producers or where politics are involved.

Poor Farming Extension Agency

The adoption of CSA will need accessibility to timely information, training, and technical assistance. Nevertheless, the extension system in Nigeria is underfunded and overused, as the number of extension agents per farmer in some states amounts to 1:10,000 on average (Lawal 2023). This negates the capacity of farmers to learn and implement new methods. In addition, not all extension agents receive proper training on the practices of CSA, which causes inconsistency or outmoded recommendations.

Fragmentation of Policy and Institution

It is necessary to develop the coordination across sectors such as agriculture, environment, water resources, and energy so that CSA can be implemented successfully. In Nigeria, the development of policy is usually made through silos and there is very less coordination between various ministries, departments and agencies. The lack of a specific national CSA strategy, inadequate inter-agency coordination, and the sharing of data are major obstacles to efficient planning and investment (Mrabet, & Moussadek, 2022). This constitutes redundancy, inefficient utilization of resources, and policy mismatch.

Insecurity on Land Tenure

The land tenure systems in most regions in Nigeria are unregistered, informal, and operate under customary law. This lack of security prevents the long-term investment in soil fertility, agroforestry, or irrigation infrastructure, which are all considered to be a part of CSA (Otitoju et al., 2023). Women and young people are especially disadvantaged, with many not having the right to farmland ownership or being able to make key decisions.

Cultural Blocks and Low Awareness

A significant number of farmers are not knowledgeable about CSA practices and fail to comprehend the significance of such practices in cases where they do not yield immediate benefits. Besides, cultural conformity and fear of change may constrain the adoption of new ways of doing things. As an example, farmers do not want to leave traditional tillage or embrace the ideas of agroforestry due to intergenerational tendencies, fear of risks, or social norms.

Infrastructural and Market Limits

Inadequate infrastructure (particularly roads, warehouses, and markets) limits the effectiveness of CSA in farmers who are to receive the benefits. The inability to access markets and value chains discourages further adoption even when climate-resilient techniques have shown they result in increased yield. Correspondingly, the reliance on digital climate information services and smart farming tools is subject to inefficient electricity and mobile networks.

Literature gaps

Though research studies on Climate Smart Agriculture (CSA) have increased around the world and in Sub-Saharan Africa, there is still notable lack of literature, especially in the Nigerian setting. Most of the research that has already been conducted has been based on the theoretical context of CSA or the technical analysis of specific practices, e.g., conservation agriculture, cropping to drought-tolerant crops with better adaptation to climate change. Nevertheless, no one has taken an end-to-end, contextual examination of the CSA practices and incorporated them into the four pillars of food security, i.e., availability, access, utilization, and stability in Nigeria.

1. Absence of Composite Evaluations that tie CSA to Food Security Results

Despite a number of studies on the adoption of CSA practices, there exists little empirical evidence relating the practices to measurable food security indicators. The majority of the studies isolate the productivity gain or adaptation effects without evaluating the overall effects on the households in terms of nutrition, food access, and dietary diversity. According to Sova et al. (2018), there is still a gap in the metrics used to assess CSA implementation and the actual food system resilience, which limits the possibilities of assessing just how transformative CSA can be on the scale.

2. Gaps in Concentrating on Socioeconomic and Institutional Motivators

Most of the studies tend to focus on agronomic methods, yet do not give enough focus to the socioeconomic and institutional conditions influencing adoption. Major issues that include land tenure insecurity, gender inequality, youth exclusion, and access to extension or finance are frequently seen as secondary matters, although they are at the center of whether CSA will succeed or fail in rural Nigeria (Totin et al., 2018). Further research is required to understand how such structural problems impact the adoption and sustainable practice of CSA practices.

3. Low geographical and gender coverage

It is worth noting that a great part of the CSA literature in Nigeria is often centred in the limited area in Nigeria (e.g., as in the Middle Belt and parts of the North), whereas less emphasis is placed on the southern and coastal states with various climate risks that include flooding and coastal erosion. Also, CSA is often analyzed without gender segmentation, though an increasing body of evidence supports the existence of unique land, input, and information access constraints with women (Yusuf et al., 2022). Studies that do not incorporate such disparities may unintentionally reinforce the current inequalities by devising methods of solution that indirectly support this disparity.

4. Unsupported Assessment of CSA-Technology Facilities

With increased availability of digital agriculture solutions, including mobile-assisted weather advisories, precision crop apps, and smart irrigation installations, surprisingly little peer-reviewed research has been published to evaluate how well such systems work, their usability and scalability in smallholder settings. Available studies tend to be oriented on the innovation itself instead of the availability of the innovations or how it will be included in the local farming system in the long term (Akinola et al., 2021).

5. Lack of Longitudinal and Cost-Benefit Analyses

There is a limited number of studies that use longitudinal data to monitor the effects of CSA interventions over the period. Likewise, there are insufficient cost-benefit analyses that determine the economic feasibility of making CSA investments (e.g., solar irrigation or agroforestry). This renders it hard to state evidence-informed choices via policymakers and investors concerning resource apportionment and methodology structure.

Methodology

In this study, a qualitative and literature-based study design was used to explore the interdependence between the Climate Smart Agriculture (CSA) practices and the food security outcomes in the Nigerian context of climate change. The systematic literature review, secondary data analysis, and policy document synthesis methodologies have been used to address the effectiveness of CSA implementation and adoption and its scalability in the Nigerian farming contexts.

The Research Design

The study design was exploratory and descriptive, which is fitted with knowledge in complex relationships among agricultural interventions, environmental change, and policy landscapes. This is a non-experimental study that builds on desk-based research and is informed by peer-reviewed literature, government reports, international development publications, and CSA project evaluations as far as they apply to Sub-Saharan Africa and Nigeria in particular.

Data Sources

a) Literature Review

A structured review was conducted using academic databases such as Scopus, ScienceDirect, Google Scholar, and JSTOR, with search terms including:

"Climate Smart Agriculture in Nigeria"

"Food security and climate change"

"CSA adoption barriers"

"Gender and CSA"

"Drought-tolerant crops in Nigeria"

"Climate adaptation in agriculture"

Articles were included if they:

Were published between 2010 and 2024

Focused on Nigeria or Sub-Saharan Africa

Addressed one or more CSA pillars (productivity, adaptation, mitigation)

b) Policy and institutional Documents

Important national policy documents reviewed include the National Agricultural Resilience Framework (NARF), National Adaptation Strategy and Plan of Action for Climate Change (NASPA-CCN), and Federal Ministry of Agriculture and Rural Development (FMARD) reports. Quality international sources were the FAO CSA Sourcebook, IPCC reports, and World Bank CSA investment profiles.

c) Secondary Data

Triangulation of data on food security indicators, climate trends, and agricultural productivity was done using data obtained through FAOSTAT, World Bank Open Data, and the National Bureau of Statistics (NBS) in Nigeria, where available.

Model of analysis

The CSA-Food Security Linkage Model, based on the FAO (2013) and adapted by Lipper et al. (2014) by mapping the practices of CSA on the four food security dimensions:

1.Availability (e.g., more yields)

2.Access (e.g., market linkages)

3.Usage (e.g., nutrition-sensitive agriculture)

4.Stability (e.g., shock resistance)

This framework has helped the study to understand the impact of different interventions in CSA on diverse elements of food security in cases of climate risks. Thematic analysis of institutional, financial, and infrastructural barriers in order to isolate the system-level constraints was conducted.

Limitations

Limitations of this study include the use of secondary information and qualitative evidence. Although the general sense gets clear due to the literature review and document analysis, there can be minimal context specificity due to the lack of primary field data/the existence of surveyor field data (farmer level). The results are conceptual and not predictive, but remain useful in guiding policy and program development in Nigeria.

Ethical Considerations

The research only entailed publicly available and published materials, and ethical consent was thus unnecessary. Citation of all sources has been done accordingly, and data privacy issues were not relevant.

Results and Discussion

The section is a synthesis of core findings of the reviewed literature, policy documents, and technical reports on the role of CSA in enhancing food security and climate resilience in Sub-Saharan Africa, with specific reference to Nigeria. It also distinguishes points of implementation blockage and feasible points of upgrading interventions of CSA.

The consequences of CSA, in terms of agricultural output and food supply

It is demonstrated that CSA technologies have a strong potential to increase yield and minimize losses caused by the climate. As an example, the use of drought-tolerant varieties of maize and cassava in northern Nigeria has led to a 20 to 40 percent increase in dry conditions (IITA, 2020). Conservation farming, especially minimum tillage and mulch, has also led to mitigating soil erosion and moisture conservation in arid regions.

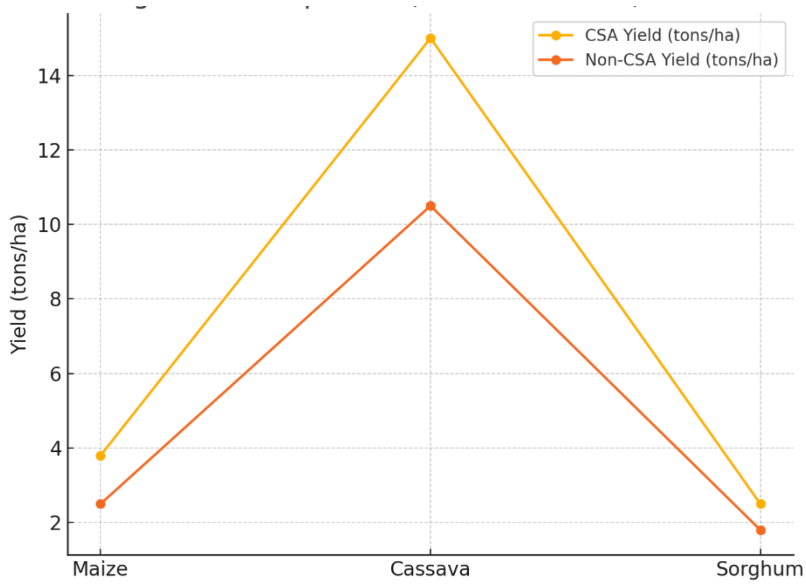


Figure 1: Average Yield Comparison (CSA vs Non-CSA Practices)

These productivity gains go straight to bolstering the availability pillar of food security by enabling seasonal hunger to be reduced and an even supply of local food to prevail even during spells of climatic extremes.

Access to Food and CSA

CSA allows farmers to boost production and decrease production risks, increasing farm incomes and expanding economic access to food. As an illustration, collected data show that agroforestry systems involving fruit trees and crops have helped households to diversify their sources of income so that they no longer rely on the contingencies in the market of crops (Garba, 2023).

The latter, however, is still limited by poor market infrastructure. The report provided in Nigeria proves that CSA-related success stories are a possibility where there are farmer cooperatives, rural roads, and ICT services, where input sources and market connections are possible. An example in point is the use of programs such as Hello Tractor (a digital mechanization platform) where CSA can be bundled to enable both access and use of mobile technologies by resource-poor farmers and offer them fewer obstacles.

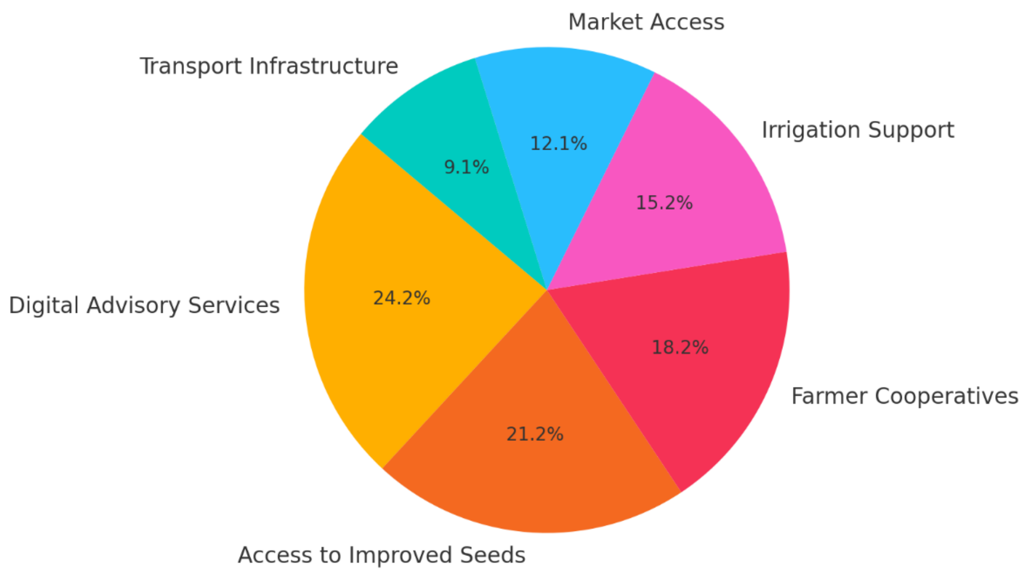


Figure 2: CSA Value Chain Support Elements with ICT and Market Access

Role of CSA in Nutrition and Food Utilization

Food utilization is also facilitated by CSA practices that help in promoting nutrition-sensitive agriculture. Micronutrient intakes and diets increase with home gardens, legume intercropping, and biofortified crops (e.g., vitamin A maize or iron-rich beans) (de la Peña et al., 2018). Moreover, the emphasis of CSA in minimizing the use of chemical substances by employing an integrated pest management and the organic method, along with the chemicals used in it, diminishes the odds associated with the harmful residue in food.

Although these results show positive gains, there is poor adoption of these practices in those communities that do not have nutrition awareness programs. To transform a food system comprehensively, there is a necessity to combine the work of CSA interventions and health and sanitation services.

Stability and Resilience through CSA

When CSA is institutionalized, the stability of food systems is significantly improved. Early maturing varieties of rice and raised bed cultivation have enabled the farmers in areas with frequent floods in southern Nigeria to adjust to reduced planting periods. Similarly, the irrigation systems that use solar energy have made the practice in the North to be able to farm during intensive periods of drought.

Additionally, CSA fosters diversification of risks by supporting mixed cropping, integrating livestock into cropping, and the use of climate forecasting models, which enable the farmers to plan beforehand. Such strategies enhance the short-term coping and the long-term adaptive capacity.

Gap Implementation and Equity Issues

Regardless of the proven advantages of CSA, its implementation is unbalanced by gender inequality, exclusion of the youth, and land rights. Women, although they assume key roles in the production of food, do not always have access to land, credit and the extension services. Likewise, numerous CSA initiatives are not designed to meet the demands of the pastoralists and urban/peri-urban farmers who are diverse in their vulnerabilities.

Moreover, the majority of the CSA interventions are introduced as pilot projects, which are frequently subject to donor funding. In the absence of institutional mainstreaming as well as sustainable financing structures CSA can become fragmented and never achieve scale.

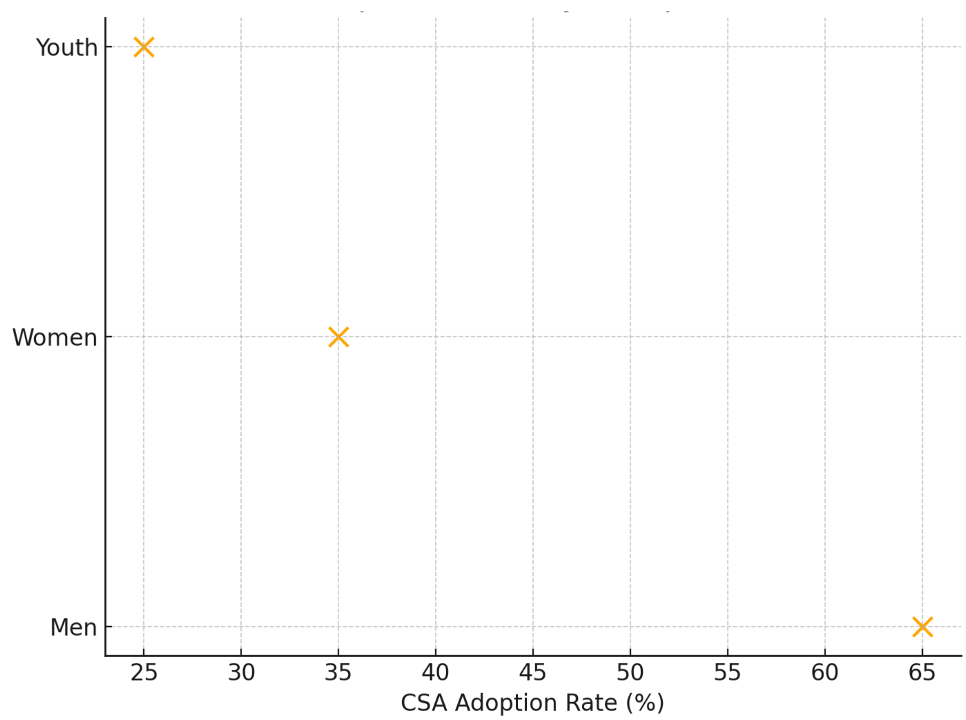


Figure 3: CSA Adoption Rates by Group

Summary of Key Contributions of CSA to Food Security Pillars

CSA Component	Food Security Pillar Addressed	Observed Impact
Drought-tolerant crops	Availability	Increased yields during rainfall variability
Market access & cooperatives	Access	Higher income, reduced price volatility
Biofortified and diverse crops	Utilization	Improved household dietary quality
Resilient farming techniques	Stability	Reduced losses during floods/droughts

Table 1: Summary of CSA Contributions to Food Security

Policy Recommendations

Strategic and inclusive policy interventions are relevant to actualize the full potential of Climate Smart Agriculture (CSA) in meeting food insecurity and climate change in Sub-Saharan Africa, and more so in Nigeria. Based on the results of the present research, the following recommendations are made:

Embed the CSA into the National Agricultural Policies

It matters significantly that CSA should become institutionalized in the Nigerian agricultural development agenda. It entails making the goals of CSAs be in line with major national plans, including the National Agricultural Technology and Innovation Policy (NATIP) and the National Adaptation Strategy and Plan of Action on Climate Change (NASPA-CCN). The incorporation of the CSA principles should be incorporated at each and every level, such as state extension programs, national investment plans, so that there is consistency and viability.

Increase Access to Finance for Smallholders

Access to finance is a key limitation to the adoption of CSA. Financial institutions and the government ought to come up with specific credit plans, subsidies, and insurance services to reduce the price of implementing or installing CSA technologies, including drought-resistant seeds, solar irrigation, and digital equipment. There should also be mechanisms such as climate risk insurance and results-based financing, which will aid resilience and innovations.

Enhancing Agribusiness Extension and Strengthening

Effective CSA is reliant on knowledgeable and empowered farmers. The immediate requirement is to carry out an agricultural extension officer training on technologies of CSA and enhancement of the extension to farmer ratio, using electronic means, mobile advisory services, and community extension practices. Gender-sensitive training deserves special consideration as women and youth must move to the center of CSA knowledge dissemination.

Encourage Availability of Local Research, Innovation, and Transfer of Technology

CSA has to be localized according to local agro-ecological and cultural settings. More funding should be accorded to research institutions to come up with location-specific CSA practices like pest-resistant crop varieties and indigenous agroforestry systems. Also, it is recommended that the speed of scaling of innovations, in particular ICT and agricultural innovations based on renewable energy, should be stimulated with the deployment of public-private partnerships (PPP).

Build Infrastructure to Serve CSA Value Chains

Policy makers need to spend on climate-resilient infrastructure, which consists of rural roads, storage facilities, solar-powered cold chains, and irrigation channels. Such infrastructures not only facilitate the CSA practices but also increase access to markets, minimize post-harvest losses, and improve food availability and income stability.

Promote Multi-Sectoral and Regional Partnership

CSA has a cross-cutting character requiring policy coherence to be valued between sectors, agriculture, environment, energy, water, and ICT. Operations that facilitate the coordination of ministries, NGOs, research institutions, and the private sector should be established at the platforms. Further, it can be said that through regional interaction between ECOWAS nations, knowledge sharing, resource pooling, and unification of CSA standards can be done in the same agro-climatic zoning.

The Observation, Test, and Expand What Works

Lastly, strong monitoring and evaluation (M&E) systems should be put in place to evaluate the effect of CSA interventions on food security and climate resilience. Evidence-based decision making will assist in identifying best practices and expanding evidence-based solutions. Governments ought to spend funds on digital data gathering mechanisms, feedback loops, and participatory assessment systems to warrant adaptive learning.

Conclusion

This paper examines the role of Climate Smart Agriculture (CSA) as a strategic solution to address the combined issues of food security and climate change in Sub-Saharan Africa, with a focus on Nigeria. The findings indicate that CSA can help improve agricultural productivity, boost resilience to climate shocks, and promote long-term sustainability of food systems.

It highlights CSA's relevance as both a mitigation and adaptation strategy by connecting practices such as drought-tolerant crop varieties, integrated soil and water management, agroforestry, and digital advisory tools with the four pillars of food security: availability, access, utilization, and stability. Evidence suggests that CSA interventions can lead to higher yields, income diversification, better nutritional outcomes, and reduced vulnerability to weather-related disruptions.

However, the research also identifies key barriers to scaling up CSA effectively. These include farmers' limited access to financial resources, weak extension systems, exclusion of women and youth, incoherent policies, and inadequate infrastructure. While pilot programs have demonstrated success at local levels, widespread implementation is hindered by poor coordination among policies, limited institutional capacity, and insufficient investment.

To address these challenges, the paper recommends integrating CSA into national agricultural policies, expanding inclusive financing models, developing climate-resilient infrastructure, and investing in local research and innovation.

It also emphasizes the importance of multi-sectoral collaboration, especially among agriculture, environment, energy, and ICT sectors, to enable coordinated large-scale adoption of CSA.

Although this study is based on secondary data and literature review, it offers a valuable synthesis of existing knowledge and policy options. Future research should focus on field-based assessments, cost-benefit analyses of CSA technologies, and longitudinal studies to evaluate how outcomes change over time.

Acknowledgement

The authors would like to profusely acknowledge the contributions of all people and organizations that have influenced development of this paper. Special thanks are given to the various researches, institutions, and policymakers whose work in the domains of climate change, agriculture, and food security gave useful knowledge in the literature review process.

We would also like to express our gratitude to our scholarly advisors and colleagues whose pieces of advice and support made the writing process run smoothly and fruitfully. They were of great help in informing depth and comprehension of this work.

At last we offer gratitude to those climate-resilient farmers, local extension agents and development practitioners in Nigeria and throughout Sub-Saharan Africa whose field practice experiences remain at the forefront of driving the adoption of evidence-based policy and action.

References

Adunola, M. P., Fayeun, L. S., & Fadara, A. B. (2021). Impact of climate change on armyworm infestation on maize in Nigeria: A review. Plant Breed. Crop Sci, 13, 158-167.

Aghimien, E. V., Akinkuoroye, O. H., & Fakolade, A. N. (2021). Assessment of Waste Associated with Timber Flitching in Bodija Plank Market, Ibadan, Nigeria. Climate Smart Agriculture and Agribusiness Development in Nigeria, 113.

Akinkuolie, T. A., Ogunbode, T. O., & Adekiya, A. O. (2025). Resilience to climate-induced food insecurity in Nigeria: a systematic review of the role of adaptation strategies in flood and drought mitigation. Frontiers in Sustainable Food Systems, 8, 1490133.

Ayanlade, A., Radeny, M., & Morton, J. F. (2018). Comparing smallholder farmers' perception of climate change with meteorological data: A case study from southwestern Nigeria. Weather and Climate Extremes, 21, 52–61. https://doi.org/10.1016/j.wace.2018.06.001

Azare, I. M., Abdullahi, M. S., Adebayo, A. A., Dantata, I. J., & Duala, T. (2020). Deforestation, desert encroachment, climate change and agricultural production in the Sudano-Sahelian Region of Nigeria. Journal of Applied Sciences and Environmental Management, 24(1), 127-132.

Bello, M. M., Yahaya, J. U., & Adamu, I. (2024). An analysis of sustainable agricultural productivity and food security in Nigeria. Journal of Political Discourse, 2(2), 45-60.

de la Peña, I., Garrett, J., & Gelli, A. (2018). IFAD RESEARCH SERIES 30-Nutrition-sensitive value chains from a smallholder perspective: a framework for project design.

Elisha, O. D., & Felix, M. J. (2021). Destruction of coastal ecosystems and the vicious cycle of poverty in Niger Delta Region. Journal of Global Agriculture and Ecology, 11(2), 7-24.

Erezi, E., Ehi, O. E., & Ayodeji, O. T. (2023). Promoting sustainable agriculture and climate resilience in African nations. Int J Agric Earth Sci, 9, 27-45.

ETIM, E. J. (2022). Gender differentials in income inequality, poverty and food insecurity among artisanal crayfish harvesting households in the Niger Delta area, Nigeria (Doctoral dissertation).

FAO. (2008). An Introduction to the Basic Concepts of Food Security. Rome: Food and Agriculture Organization.

FAO. (2012). The State of Food Insecurity in the World 2012. Rome: FAO.

FAO. (2013). Climate-Smart Agriculture Sourcebook. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i3325e/i3325e.pdf

FAO. (2017). Climate-Smart Agriculture: Building Resilience to Climate Change. FAO.

FAO. (2022). Nigeria Country Programming Framework 2023–2027. Food and Agriculture Organization.

FMARD. (2020). Agricultural Transformation Agenda Support Program II (ATASP-II). Federal Ministry of Agriculture and Rural Development.

Gana, I. M., Sadiq, K. H. A. D. I. J. A. T., Adamu, O. T., & Aliyu, M. O. H. A. M. M. E. D. (2024). The Interplay between Climate Change and Food Security in Nigeria: Challenges and Opportunities. Journal of Political Development.

Garba, M. H. (2023). Assessment of Potentials of Fruit Trees on Food Security of Rural Farmers in Niger State, Nigeria (Doctoral dissertation).

IPCC. (2021). Sixth Assessment Report: Impacts, Adaptation, and Vulnerability. Intergovernmental Panel on Climate Change.

Johnson, J. S. (2018). Heat stress: impact on livestock well-being and productivity and mitigation strategies to alleviate the negative effects. Animal Production Science, 58(8), 1404-1413.

Lembani, D. K., Phiri-PhD, B. S., & Ivan, K. B. Sustainable Agriculture and Climate Resilience in Sub-Saharan Africa.

Makate, C. (2019). Effective scaling of climate smart agriculture innovations in African smallholder agriculture: A review of approaches, policy and institutional strategy needs. Environmental science & policy, 96, 37-51.

Mashi, S. A., Inkani, A. I., & Oghenejabor, O. D. (2022). Determinants of awareness levels of climate smart agricultural technologies and practices of urban farmers in Kuje, Abuja, Nigeria. Technology in Society, 70, 102030.

Mutengwa, C. S., Mnkeni, P., & Kondwakwenda, A. (2023). Climate-smart agriculture and food security in southern Africa: a review of the vulnerability of smallholder agriculture and food security to climate change. Sustainability, 15(4), 2882.

Nigerian Meteorological Agency (NiMet). (2020). 2020 Seasonal Rainfall Prediction (SRP). Abuja: NiMet.

Ojeilua, C. H., Folorunso, A. E., Eze, F. N., Okaah, E. L., & Alonge, O. R. (2025). Evolutionary Adaptations in Drought-Resilient Crops and Their Impact on Agricultural Sustainability in Nigeria. African Journal of Agricultural Science and Food Research, 19(1), 44-64.

Olagunju, T. E. (2015). Drought, desertification and the Nigerian environment: A review. Journal of Ecology and the Natural Environment, 7(7), 196–209. https://doi.org/10.5897/JENE2015.0516

Olanrewaju, C. C., Chitakira, M., Olanrewaju, O. S., & Louw, E. (2019). Impacts of flooding on coastal communities in Nigeria: A case study of Esan South East LGA. Jàmbá: Journal of Disaster Risk Studies, 11(1), 1–9. https://doi.org/10.4102/jamba.v11i1.585

Oseghale, A. I., Nmadu, J. N., Bako, R. U., Olarewaju, O., Jirgi, A. J., Yisa, E. S., ... & Mohammed, U. S. (2024). Sustainable Food Supply: The Interplay between Population Growth and Land Productivity Changes as a Pathway to 2030 and Beyond for Nigeria. Asian Research Journal of Agriculture, 17(2).

Prince, A. I., Obiorah, J., & Ogar, E. E. (2023). Analyzing the critical impact of climate change on agriculture and food security in Nigeria. Int. J. Agric. Earth Sci, 9, 42023.

Sarker, M. N. I., Wu, M., Chanthamith, B., Yusufzada, S., Li, D., & Zhang, J. (2019, May). Big data driven smart agriculture: Pathway for sustainable development. In 2019 2nd international conference on artificial intelligence and big data (ICAIBD) (pp. 60-65). IEEE.

Singh, C., & Nath, R. (2020). Farming system and sustainable agriculture: Agricultural reform. Sgoc Publication.

Tesfaye, L., Alemayehu, S., Jalango, D., Karanja, S., Magambo, G., Ghosh, A., ... & Jaquet, S. (2023). Climate-smart agriculture investment plan for Ethiopia.

Thornton, P. K., Whitbread, A., & Baedeker, T. (2018). A framework for priority-setting in climate smart agriculture research. Agricultural Systems, 167, 161–167. https://doi.org/10.1016/j.agsy.2018.09.003

Totin, E., Segnon, A. C., Schut, M., Affognon, H., Zougmoré, R. B., & Kossou, D. (2018). Institutional logics and adaptation pathways of Climate-Smart Agriculture in West Africa. Global Environmental Change, 53, 1–11. https://doi.org/10.1016/j.gloenvcha.2018.08.011

Usman, M., Ibrahim, F., & Oyetola, S. O. (2018). Sustainable agriculture in relation to problems of soil degradation and how to amend such soils for optimum crop production in Nigeria. Int. J. Res. Agric. Food Sci, 4, 1-17.

World Food Programme. (2023). Nigeria Food Security Outlook. Retrieved from https://www.wfp.org/countries/nigeria

Precision Livestock Farming Practices in Cattle Breeding

Gökçe Özdemir[1]

[1] Department of Zootechnics and Animal Nutrition, Faculty of Veterinary Medicine, Sivas Cumhuriyet University, 58140, Sivas, TÜRKİYE
gokceozdemir@cumhuriyet.edu.tr

Abstract

Increasing global demand for animal-based products is forcing farmers to expand and grow their operations. There is a rapid progress in the livestock sector towards intensive and specialized precision livestock farming systems where maximum productivity per animal is targeted and production areas are controlled. This process, which we can describe the livestock revolution, started slowly but has shown rapid growth and progress. In cattle breeding, the use of new technologies to manage animal production using precision animal husbandry, process engineering principles and techniques is becoming widespread. In cattle breeding; it makes regulations for the use of precision livestock farming technologies in many areas such as animal monitoring, identification, health protection, feeding, manure management and climate control in order to achieve production standards such as efficiency, food safety, animal welfare and sustainability, to monitor animal health more easily, to improve environmental conditions and to optimize production processes. In this study, it was aimed to examine the application status and potential of developing digital technologies such as Precision Livestock Farming (Livestock 4.0) in cattle breeding, as well as to comparatively address issues such as the effects, benefits and risks of these applications on animal health and welfare in different dimensions.
Key Words: *Cattle, Precision livestock farming, Animal health, Animal welfare*

Büyükbaş Hayvan Yetiştiriciliğinde Hassas Hayvancılık Uygulamaları

Özet

Hayvansal kaynaklı ürünlere yönelik küresel talebin giderek artması, çiftçileri faaliyetlerini genişletmeye ve büyütmeye zorlamaktadır. Hayvancılık sektöründe hayvan başına maksimum üretkenliğin hedeflendiği, üretim alanlarının kontrol edildiği yoğun ve uzmanlaşmış hassas hayvancılık sistemlerine doğru hızlı bir ilerleme yaşanmaktadır. Hayvancılık devrimi diyebileceğimiz, bu süreç yavaş başlayıp hızlı bir büyüme ve ilerleme göstermiştir. Büyükbaş hayvan yetiştiriciliğinde de, hassas hayvancılık süreç mühendisliği prensip ve tekniklerinden faydalanılarak, hayvansal üretimi yönetmek için yeni teknolojilerin kullanımı yaygınlaşmaktadır. Büyükbaş hayvan yetiştiriciliğinde; verimlilik, gıda güvenliği, hayvan refahı ve sürdürebilirlik gibi üretim standartlarının yakalanması ve hayvan sağlığının daha kolay izlenebilmesi, çevre koşullarının iyileştirilebilmesi ve üretim süreçlerinin optimize edilebilmesi amacıyla hayvanların izlenmesi, tanımlanması, sağlık koruma, besleme, gübre yönetimi ve iklim kontrolü gibi birçok alanda hassas hayvancılık teknolojilerin kullanımına yönelik düzenlemeler yapılmaktadır. Bu çalışmada, büyükbaş hayvan yetiştiriciliğinde Hassas Hayvancılık (Hayvancılık 4.0) gibi gelişen dijital teknolojilerinin hayvancılıkta uygulanma durumu ve potansiyelinin incelemesi yanında bu uygulamaların hayvan sağlığı ve refahı üzerine etkileri, yararları ve riskleri gibi konular karşılaştırılmalı olarak ele alınması amaçlandı.
Anahtar Kelimeler: *Büyükbaş hayvan, Hassas hayvancılık, Hayvan sağlığı, Hayvan refahı*

Giriş

Son yıllarda, tarım ve özellikle de hayvancılık sektörü, endüstrileşme sürecinin sonucu olarak dijital yenilik ve teknolojilerin kullanımı ile dijitalleşme sürecinden etkilenen önemli sektörlerdir (Goller et al., 2021; Schillings et al., 2021; Morrone et al. 202). Birçok çiftçi, girdi kaynaklarını daha verimli ve etkili bir şekilde değerlendirmek ve çalışma süreçlerini otomatikleştirmek amacıyla entegre sistemlerin kullanılmasında öncülük ederek, hayvancılık sektöründe önemli potansiyele sahip, hassas veya akıllı dijital teknolojileri üretimlerinde kullanmaktadır (Goller et al., 2021). Hassas hayvancılık uygulamalarının üretimde yaygınlaşmasının alt yapısını hazırlayan teknolojik gelişmeler, çiftçilerle birlikte dünya genelinde uzmanlarında hayvancılıkta hayvan sağlığı, hayvan refahı ve çevresel etki yönetimi gibi önemli konularda bu teknolojilerin kullanımına yönelik çalışmalar yürütmelerini teşvik etmektedir (Vázquez-López et al. 2021; Schillings et al., 2021; Kraft et al., 2022; Morrone et al. 2022).

Büyükbaş hayvan yetiştiriciliğinde, Hassas Hayvancılık, prensip ve tekniklerinin sürü yönetim sistemlerine entegre edilmesi; verimli, sürdürülebilir ve karlı bir hayvancılık üretim süreçlerinin kurunum aşamasından itibaren hayvanların izlenmesi, hayvan sağlığı ve refahı, besleme, çevre kontrolü, üretimin iyileştirilmesi ile

optimizasyonunun sağlanmasında ve karar verme süreçlerini iyileştirmede yetiştiricilere yardımcı olmaktadır (Cabrera et al., 2020; Kraft et al., 2022; Morrone et al. 2022; Tuvay ve Ermetin, 2023). Çiftlik yönetiminde hassas hayvancılık uygulamalarında kaliteli, gerçek zamanlı ve büyük miktarda veri akışı üreten kameralar, mikrofonlar, sensörler, dronlar, mikroişlemciler, kablosuz ağ sistemleri, internet bağlantıları, hücresel iletişim, bulut sistemleri, nesnelerin interneti, yapay zeka, büyük veri gibi teknolojik yeniliklerden faydalanılmaktadır. Büyükbaş hayvan yetiştiriciliğinde, sürü yönetim sistemlerine üretim otomasyonu ve mekanizasyonunu sağlamak amacıyla entegre edilebilmiş; tam otomatik süt sağım robotları, giyilebilir sensörler, otomatik yemleme makineleri ve hayvanları ayırmaya yardımcı olan otomatik kapı sistemleri gibi eyleme geçirilmiş örnekler yaygın bir şekilde kullanılmaktadır (Cabrera et al., 2020; Goller et al., 2021; Neethirajan and Kemp, 2021; Kraft et al., 2022; Morrone et al. 2022; Tuvay ve Ermetin, 2023).
Bu çalışmada, büyükbaş hayvan yetiştiriciliğinde Hassas Hayvancılık (Hayvancılık 4.0) gibi gelişen dijital teknolojilerinin hayvancılıkta uygulanma durumu ve potansiyelinin incelemesi yanında bu uygulamaların hayvan sağlığı ve refahı üzerine etkileri, yararları ve riskleri gibi konular farklı boyutlarda ele alınması amaçlandı.

Büyükbaş Hayvan Yetiştiriciliğinde Hassas Hayvancılık Uygulamaları

Hayvansal kaynaklı ürünlere yönelik küresel talebin giderek artması, çiftçileri faaliyetlerini genişletmeye ve büyütmeye zorlamaktadır (Morrone et al. 2022). Hayvancılık sektöründe hayvan başına maksimum üretkenliğin hedeflendiği, üretim alanlarının kontrol edildiği yoğun ve uzmanlaşmış hassas hayvancılık sistemlerine doğru hızlı bir ilerleme yaşanmaktadır (Berckmans, 2017; Yaman ve ark., 2021). Hayvancılık devrimi diyebileceğimiz, bu süreç yavaş başlayıp hızlı bir büyüme ve ilerleme göstermiştir (Berckmans, 2017; Yaman ve ark., 2021). Büyükbaş hayvan yetiştiriciliğinde de, hassas hayvancılık süreç mühendisliği prensip ve tekniklerinden faydalanılarak, hayvansal üretimi yönetmek için yeni teknolojilerin kullanımı yaygınlaşmaktadır (Cabrera et al., 2020; Schillings et al., 2021; Kraft et el 2022; Morrone et al. 2022; Ermetin, 2023).
Büyükbaş hayvan yetiştiriciliğinde; verimlilik, gıda güvenliği, hayvan refahı ve sürdürebilirlik gibi üretim standartlarının yakalanması ve hayvan sağlığının daha kolay izlenebilmesi, çevre koşullarının iyileştirilebilmesi ve üretim süreçlerinin optimize edilebilmesi amacıyla hayvanların izlenmesi, tanımlanması, sağlık koruma, besleme, gübre yönetimi ve iklim kontrolü gibi birçok alanda hassas hayvancılık teknolojilerin kullanımına yönelik düzenlemeler yapılmaktadır (Cabrera et al., 2020; Schillings et al., 2021; Morrone et al. 2022; Tuvay ve Ermetin, 2023; Ermetin, 2023). Hassas hayvancılık yaklaşımı, hayvan davranışlarını sürekli olarak hayvan üzerindeki veya ortamdaki sensörler (örn. sıcaklık ölçümü, GPS konumu, ivmeölçer verileri), gerçek zamanlı görüntü veya ses cihazları kullanılarak toplanması ve verilerin analizi üzerine kurulmuştur. Görüntü ve ses analizi, fiziksel temas gerektirmemesi, enfeksiyon veya hastalık bulaşma riskinin olmaması, ölçüm yapılırken hayvan davranışını etkileme riskinin olmaması, sensörleri canlı hayvanlardan geri alma ihtiyacının olmaması ve tek bir kamera veya mikrofonun geniş bir hayvan grubunu izleyebilmesi gibi nedenlerle hassas hayvancılık uygulamaları hayvancılıkta zaman, enerji ve maliyet gibi birçok konuda da büyük avantaj sağlamaktadır (Berckmans, 2017; Schillings et al., 2021; Neethirajan and Kemp, 2021; Kraft et al., 2022; Tuvay ve Ermetin, 2023; Ermetin, 2023).
Sürü yönetimi, sağım sistemi, genetik ve genomik test edilen hayvanların pedigri ve DNA kayıtları, süt verimi, laktasyon bilgileri, süt yağı ve protein içeriği, gibi süt bileşiminin kayıtları, rasyon bileşimi, günlük ortalama yem tüketim, büyüme performansı gibi hayvanlarla ilgili kayıtlar ve maliyette dahil çiftlikte sürekli üretilen veri akışları olup, çiftçiler için mevcut olan tüm verilere erişmek ve bu verileri analiz ederek yönetime entegre etmek ve çiftliklerde karar alma süreçlerini iyileştirebilmek amacıyla hassas hayvancılık uygulamaların kullanılmaktadır (Cabrera et al., 2020). Çiftlik yönetimi sürekli evrildiğinden hassas hayvancılık uygulamalarının sürü yönetim sistemlerine entegre edilmesi ile, kaliteli, gerçek zamanlı toplanan verilerin doğru şekilde analiz edilmesi, yetiştiricilere hayvanlarının besleme ve sağlık sorunlarını tespit etmede, üremeyi optimize etmede ve genel üretim sistemini iyileştirmede yardımcı olabilmektedir. (Cabrera et al., 2020). Sensörler, kameralar veya mikrofonlar gibi teknolojileri kullanan çeşitli sistemler, hayvanlar üzerinde tespit edilen verileri veya anormallikleri, çiftçilere çeşitli cihazlar aracılığıyla doğrudan iletebilmekte ve çiftçilerin erken müdahale etmesine olanak sağlamaktadır (Schillings et al., 2021; Morrone et al. 2022; Ermetin, 2023).

Hayvan Tanıma ve Takip Sistemleri

Sığırcılık sektöründe, hayvanların otomatik olarak tanıma sistemleri ve otomasyonun kullanımı, birçok ülkede hızla yaygınlaşmaktadır. En önemli örnekleri; otomatik sağım sistemi, otomatik besleme sistemi, otomatik temizleme ve yataklama sistemleridir (Kraft et al., 2022; Morrone et al. 2022; Tuvay ve Ermetin, 2023).
Sürü yönetimi için, modern yazılımlar kullanılarak, her ineğin tek tek ve sürüdeki tüm ineklerin mevcut verileri de dahil olmak üzere kendi veri kümelerinin oluşturulması, her bir hayvanın tanımlanması ve takip edilmesi çok önemlidir (Kraft et al., 2022; Morrone et al. 2022; Tuvay ve Ermetin, 2023). Bu sistemler üzerine yürütülen çalışmalarda; farklı vücut renklerine sahip hatta vücut renkleri birbirine çok benzeyen hayvanlarda dahil %91 doğrulukla sığırların tanınabildiği bildirilmektedir. Yine, drone tabanlı bir sistem kullanılarak; yüksek bir doğrulukla (%91,9 ve %94,4) serbestçe hareket eden sürülerdeki inekleri tek tek tanımlamak için otomatik bir vücut deseni tanıma sistemi geliştirildiği ve otomatik hayvan tanımlama ve izleme tekniklerinin ekstansif çiftlik

sistemlerinde de kullanılabildiği bildirilmektedir (Morrone et al. 2022). Bu sistemlerin çalışma mantığında; görüntü dizilerini kullanarak sığırları tanımlamak için derin öğrenme tabanlı bir çerçeve önerildiği ve bu çerçevenin, Evrişimsel Sinir Ağı (CNN) ve Çift Yönlü Uzun Kısa Süreli Bellek (BiLSTM) ağlarının avantajlarını birleştirdiği vurgulanmaktadır (Morrone et al. 2022).

Çevresel Faktörleri İzleme

Hayvancılık sektörünün, atmosferdeki amonyak (NH_3) emisyonlarının yaklaşık %90'dan, metan (CH_4) emisyonlarının %37'sinden ve azot oksit (N_2O) emisyonlarının %65'inden sorumlu olması sebebiyle çevresel etkisinin büyük bir sorun olduğu bildirilmektedir. Hassas Hayvancılık, hayvan verimliliğini genetik potansiyeline yaklaştırarak yem kullanımını azaltmaya, gübre miktarını düşürmeye ve üretkenliği artırmaya yardımcı olabileceği, bunun da çevresel etkiyi azaltmada ciddi bir katkı sağlayabileceği öngörülmektedir (Berckmans, 2017). Örneğin; gruplama yönetimi ile her beslenme grubu için hesaplanan bir inek listesine uygun rasyon formulasyonu hazırlanması, yem maliyetlerini inek başına yılda 99 dolara kadar azaltma potansiyeline sahip olduğu ve inek başına yıllık azot atılım miktarını yılda 15.5 kg azalttığı bildirmektedir (Cabrera et al., 2020).

Hava sıcaklığı, nem, su kalitesi gibi çevresel faktörlerin izlenmesi, aynı zamanda, hayvan sağlığı ve refahının iyileştirilmesinde önemli etkileri olabilmektedir. Bu amaçla, barınaklarda çevresel faktörleri izleyen sistemler geliştirilmektedir. Özellikle süt çiftçiliklerinin sabit mekansal yapısı sayesinde barınak hava kalitesini etkileyen toksik molekül konsantrasyonları, nem, pH, CO_2, sıcaklık veya oksijen seviyeleri gibi çeşitli parametrelerin görüntü ve sensör teknolojilerine dayan sistemler aracılığıyla ölçülerek, takipleri gerçekleştirilebilmektedir. Hayvanların barınak içerisinde toplanması ve dağılımı gibi hareketleri takip etmek ve konforlarını sağlamada kolaylık sağlayacak, ısıtma/havalandırma koşullarına ilişkin çevresel değişkenleri ölçerek barınak içerisinde düzenlemeler yapmaya imkan sağlayacak ticari cihazlar, sistemler geliştirilmiştir (Jo et al., 2018; Schillings et al., 2021; Kraft et al., 2022; Tuvay ve Ermetin, 2023).

Isı stresi gibi çevresel faktörler süt ineklerinde duygu durumlarını, biyolojik fonksiyonlarını ve doğal yaşam davranışlarını etkileyen fizyolojik değişikliklere neden olabilmektedir. Bu nedenle ısı stresinin inekler üzerindeki etkisinin değerlendirilmesi, makine öğrenme modellerinin kullanımı için başka bir uygulama alanı sunmaktadır (Cockburn, 2020). Araştırmacılar, çevresel ısı stresine verilen fizyolojik tepkilerin tahmin edilmesine ve derecelendirilmesine olanak sağlayan daha ileri analizlerde kullanabilmektedirler. Bu algoritmalar, çevresel parametrelerin eşik değerlerinin hesaplanması yoluyla çiftçilere, hayvanları üzerindeki ısı stresini azaltacak önlemleri uygulama zamanını belirlemede ve karar vermelerinde destek olabilmektedir (Cockburn, 2020).

Otomatik süt sağım sistemleri

Otomatik süt sağım sistemleri, tüm dünyada süt hayvancılığı sektöründe devrim yaratmıştır. Bu sistem, sağım işleminin makineler tarafından yapılmasının yanı sıra, çiftlik sisteminin işleyişinde de iyileştirmeler sunmaktadır. Artık sağım belirli zamanlarda yapılmamakta, bunun yerine inekler otomatik süt sağım sistemleri sayesinde ne zaman sağılacaklarını özgürce seçerek sağım sürecini 24 saatlik bir döngüye yayılmasını sağlamaktadır. Veri toplama çalışmalarında, yapılandırılmış veri tabanlarında toplanan verilerin ineklerin bireysel koşullarını ve performansını karakterize edebilmek amacıyla geliştirilmiş modeller kullanılmaktadır. Son çalışmalarda, makine öğrenimi teknikleri ve rastgele orman algoritması kullanılarak tek bir ineğin günlük süt üretimi ile çevresel koşulları ilişkilendiren modeller geliştirilmiştir (Cockburn, 2020; Goller et al., 2021; Kraft et al., 2022; Morrone et al. 2022).

Bireysel otomatik sağım sisteminin otomatikleştirilmiş sağım süreci adımları; ineğin bir RFID çipi aracılığıyla tanımlama, memelerin temizlenmesi, süt kalitesinin kontrol edilmesi, sağım başlıklarının ineğin bireysel memelerine tanınması ve uygulanması, ineğin akış kontrollü sağımı, sağım başlıklarının çıkarılması ve memelerin daldırma meme metoduyla son meme temizliği şeklinde bir akış sisteminden oluşmaktadır (Kraft et al., 2022).

Kızgınlık Tespiti

Kızgınlık tespiti, süt sığırcılığı endüstrisinde en önemli sürü yönetim uygulamalarından biridir. Süt sığırcılığında, verimlilik ve hastalık kontrolünde çiftçilere yardımcı olan kızgınlık tespitini sağlayan çeşitli sistemler ve yazılımlar bulunmaktadır. Kızgınlık tespiti amacıyla geliştirilmiş otomatik aktivite sistemleri; çıktıları veya analiz edilecek değişkenler (örneğin, adım sayıları, hareket ivmesi, geviş getirme sıklığı, yatma süresi) açısından çeşitlilik göstermektedir. Örneğin, boyuna monte edilen bir cihaz preovulatuar evrelerin %71'ini tespit etmiş, kaydedilen ovulasyonların yalnızca %13'ünü kaçırmıştır. Pedometre ölçümleriyle yapılan bir araştırmada ise kızgınlık dönemlerinin büyük bir kısmının tespit edilebildiği bildirilmiştir. Serbest duraklı ahırlarda da, gerçek zamanlı konum belirleme sistemleri, ineklerin hareket ve hız verilerini kullanılarak, analiz edilerek kızgınlık tespiti için kullanılabilmektedir (Cockburn, 2020; Morrone et al. 2022).

Hastalıkların Erken Tespiti ve Sağlık Koruma

Hastalığın erken dönemde tespit edilmesi, erken tedavi yapılabilmesi için hastalığa ilişkin klinik belirtilerin varlığının hızlı bir şekilde gözlemlenmesi gerekmektedir. Ancak bu çiftçinin muhakemesine ve tecrübesine

bağlıdır (Berckmans, 2017; Carpentier et al., 2018; Schillings et al., 2021). Artan hayvan sayısı nedeniyle büyük hayvan grupları içinde hayvan sağlığının sürekli izlenmesi büyük bir sorun olup büyük gruplarda hastalıklar çok ciddi sorunlar yaratabilmekte, hassas hayvancılık uygulamaları sayesinde, özellikle büyük gruplar içerisinde hayvanların bireysel ve gerçek zamanlı izlenmesi hayvanlarının sağlığını ve refahını korumada büyük çözümler sağlanabilmektedir (Berckmans, 2017; Kraft et al., 2022; Morrone et al. 2022). Sığırlarda vücuda monte edilen ivmeölçerler, aktivite verilerine dayanarak buzağılama, kızgınlık ve topallığı tespit etmek için kullanılabilirken, makine öğrenimi ile birlikte kameralar ayakta ısının, vücut kondisyon skorlarının belirlenmesine, topallığın değerlendirilmesine ve ağırlığın tahmin edilmesine yardımcı araçlar olarak kullanılmaktadır. Retikuluma yerleştirilen boluslar ayrıca kızgınlık, buzağılama ve vücut sıcaklığı veya pH gibi fizyolojik faktörleri izlemek için ve kulak sensörleri ise sıcaklık ölçümü amacıyla kullanılmaktadır (Cockburn, 2020; Schillings et al., 2021; Neethirajan and Kemp, 2021; Tuvay ve Ermetin, 2023; Ermetin, 2023).
Modern süt sığırcılığında ciddi ekonomik kayıplara neden olan ve en büyük sorunlarından biri Topallık'tır (Van Hertem et al., 2016; Kang et al., 2020). Topallık yalnızca hayvanın sağlık ve refahını etkilemekle kalmaz, aynı zamanda ineklerin süt üretimi ve üreme kapasitesinin de azalmasına sebep olmaktadır. Topallığın erken tespit edilmesi, hayvanların iyileşme oranını artırır ve özellikle tedavi maliyetlerine bağlı ekonomik kayıpların azaltılmasına da olanak sağlar (Van Hertem et al., 2016; Kang et al., 2020; Morrone et al. 2022). Van Hertem et al., 2016 bir çalışmalarında, yüksek hassasiyet gösteren sensörlerle makine öğrenmeden de faydalanarak, yedi spesifik değişkenin (yürüme hızı, sırt duruşu ölçümü, gündüz aktivitesi, süt verimi, laktasyon aşaması, süt pik akış hızı ve süt pik iletkenliği) kombinasyonunu ile geliştirdikleri bir modelin; dört seviyeli topallık sınıflandırmasında doğrulu oranının %60.3 olduğu ve modelin ikili topallık sınıflandırmasında (topallayan-topallamayan) doğruluk oranının %79.8'e yükseldiği, duyarlılık oranının %68.5 ve özgüllük oranının ise %87.6 olduğunu bildirmişlerdir (Van Hertem et al., 2016). Bir başka çalışmada; bilgisayar görüş teknolojisi ve derin öğrenme teknikleri kullanılarak, inek bacak konumunu yüksek doğrulukla ve hızlı bir şekilde tespit edilebildiği ve entegre yaklaşım ile geliştirilen topallık tespit algoritması ile ineklerin topallık durumunu %96 doğrulukla sınıflandırılarak, %93 doğrulukla topal toynağın belirlendiği, özellikle hafif ve orta şiddette topallık tespitinde iyi sonuçlar alındığı bildirmektedirler (Kang et al., 2020). Süt sığırlarında topallığı tespit etmek için eşik tabanlı kümeleme ve makine öğrenme sınıflandırması kullanılan uçtan uca bir nesnelerin interneti (IoT) uygulamasının topallığın erken teşhisini sağladığı ve süt ineklerinde mastitis ve ketosis gibi hastalıkların tespiti için de bu uygulamaların kullanılabileceği bildirilmektedir (Cockburn, 2020; Schillings et al., 2021; Morrone et al. 2022). Topallık ve stresin belirlenmesine yardımcı olabilmek amacıyla pedometrelerden de faydalanılmaktadır. Pedometreler, her bir hayvanın bir günde attığı toplam adım sayısını objektif olarak ölçebilmektedir. Bu sistem kullanılarak geliştirilen bir algoritma ile hayvanların kat ettiği toplam mesafede hesaplanabilmektedir. Ayrıca, yemek borusuna yerleştirilen rumen ve retikulumun sıcaklık ve pH değerlerini izlemek için kullanılan, kablosuz intraruminal bolus sensörlerinden, ruminal asidoz ve hipokalsemi gibi hastalıkların tespitinde faydalanılmaktadır. Birden fazla stres, hastalık veya fiziksel acı noktasını algılamak amacıyla geliştirilmiş sensörler ve benzeri cihazların birbirleriyle kombinasyon halinde kullanılabildiği de bildirilmektedir (Neethirajan and Kemp, 2021).
Buzağı yetiştiriciliğinde, sığır solunum yolu hastalığı (BRD) önemli bir sorun olup, hayvanın refahının bozulmasına ve enfekte hayvanların tedavisi ve bakımı için ekstra uzmanlık, iş gücü ve masraf gibi ciddi ekonomik kayıplara sebep olmaktadır. Solunum yolu hastalıkları için önemli klinik belirti öksürüktür. Bu nedenle, bir buzağıhanede öksürüğün izlenmesi, solunum yolu enfeksiyonu vakalarını çok şiddetli hale gelmeden önce tespit etme ve hastalığın olumsuz etkilerini sınırlama fırsatı yaratmaktadır. Buzağı öksürük seslerinin tespiti için algoritma geliştirilmiş bir çalışmada; algoritmanın, özellikle net öksürükler için, %84.2'den %100'e kadar yüksek kesinlikle iyi çalıştığı bildirilmiştir. Veri miktarının sınırlı veya çevresel gürültünün yüksek olduğu durumlarda oranın düşebildiği ve farklı buzağı barınakları ile çevresel faktörlerin (hava koşulları, yatak malzemesi, hayvan sayısı, ırkı, yaşı gibi) algoritmanın yanlış pozitif sayısını etkileyebildiği bildirilmektedir (Carpentier et al., 2018). Solunum hızı parametresi, sığır sağlığı, ağrı, stres ve hastalık gibi refah durumlarını değerlendirmek için yaygın olarak kullanılmaktadır. Kızılötesi termografi (IRT) kullanılarak soluma ve soluk verme sırasında burun delikleri etrafındaki termal dalgalanmalara dayalı bir şekilde buzağılarda solunum hızını invazif olmayan bir şekilde ölçerek teşhis yöntemi olarak kullanılmaktadır (Lowe et al., 2019; Schillings et al., 2021; Morrone et al. 2022).
Klinik mastitis başlangıcının sürekli tahmini ve erken teşhisini sağlamak amacıyla geliştirilmiş olan model ile, sağım sistemi ve yönetim verileri kullanılarak, risk taşıyan ineklerin klinik mastitis vakasının bildirilmesinden önceki son 5 sağım verisi kullanılarak başarılı bir şekilde klinik mastitisin belirlenebildiği bildirilmektir (Cabrera et al., 2020). Bu uygulama ile, ineklerin çeşitli verileri makine öğrenme teknikleri kullanılarak analiz edilip, ilk laktasyon klinik mastitis riski yüksek olan ineklerin tespit edildiği bildirilmektedir (Cabrera et al., 2020).

Hayvan Performansları ve Yem İzleme

Süt sığırcılığında dijital teknolojiler, buzağıdan yetişkinliğe kadar hayvanların büyüme ve gelişme aşamalarını daha iyi anlamak için de kullanılabilmektedir (Neethirajan and Kemp, 2021). Hayvanların yeme-içme alışkanlıklarındaki değişiklikler, hayvanın sağlık sorunlarının birer göstergesidir. Hayvanların yeme-içme davranışları ve mide bağırsak sağlığını izlemek için hassas hayvancılık teknolojilerinin kullanılması, susuzluk, açlık veya mide-bağısak hastalıkları gibi olumsuz etkilerin hayvanın üzerindeki baskıyı en aza indirmek için kullanılmaktadır. Bu verilere dayalı olarak yeterli yönetim kararları almaları noktasında yetiştiricilere ek destekte sağlamaktadır. Bu yolla, çiftlikte hayvan refahının iyileştirilmesinde önemli bir potansiyele sahip olabileceği bildirilmektedir (Cockburn, 2020; Schillings et al., 2021; Tuvay ve Ermetin, 2023). Süt ineklerinin yeme ve geviş getirme davranışlarının izlenmesi, hastalıkların tespit edilmesi ve verimlilik değerlendirmesi için kullanılmaktadır. Sığırlarda, makine öğrenmeyle birleştirilmiş bilgisayar görüşünü kullanan akıllı kamera sistemleri ile, hayvanların yeme süresi ve yem kullanılabilirliğini grup düzeyinde izlenebilmektedir. Yine, 3D ivmeölçerlerle donatılmış boyun tasmaları ile hayvanlarda bireysel olarak geviş getirme ve yeme süresi sürekli olarak izlenebilmektedir (Cockburn, 2020; Schillings et al., 2021; Neethirajan and Kemp, 2021; Tuvay ve Ermetin, 2023). Süt ineklerinde yeme ve geviş getirme aktivitelerini izleyen ve aynı zamanda Rumi Watch olarak da bilinen bir burun bandı sensörü, çiftçilerin stresli hayvanları tanımlamasına ve yönetmesine destek olabildiği ve başarılı bir performans sergilediği bildirilmektedir (Neethirajan and Kemp, 2021; Morrone et al. 2022). Gastrointestinal sağlık için, sığır retikulumunda pH ve sıcaklığı ölçen boluslar kullanılırken, yine sığırlarda ticari olarak satılan boluslar ve sensörler aracığı ile hayvanın su tüketimi de izlenebilmektedir (Cockburn, 2020; Schillings et al., 2021; Neethirajan and Kemp, 2021). Akustik izleme kullanarak serbest dolaşan sığır, keçi ve koyunlardaki sindirim davranışları takip edilebilmektedir (Schillings et al., 2021). Sığır üretim sisteminde aktivite, yemleme, içme davranışlarını izlemek ve envanter yönetimi amacıyla geliştirilen bir cihaz ise çene ve baş hareketlerinden kaynaklanan ivmeleri tespit ederek beslenme davranışını ölçmektedir (Morrone et al. 2022).

Beslenme gruplandırması, süt çiftliklerinde maliyeti kontrol etmek, verimliliği ve üretkenliği artırmak için potansiyel olarak kullanılan etkili bir stratejidir. Bu strateji, laktasyondaki inekleri daha homojen beslenme gereksinimleri olan gruplarda toplamaktan oluştuğu ve grup besleme yönetim stratejilerin ekonomik ve üretken faydalarının olduğu bildirilmektedir (Cabrera et al., 2020). Gruplama yönetimi uygulama aracılığıyla sağlanan sağım, besleme ve yönetim yazılımı ve diğer veri akışlarını sürekli olarak entegre edilen model ile inekler laktasyon sırası (ilk laktasyon, ilk laktasyondan fazla), laktasyon evresi (yeni, erken, tepe ve geç laktasyon), süt verimi gibi verilere göre gruplanmakta; her beslenme grubu için bir inek listesi saplamakta ve gruba uygun rasyon formulasyonu için uygun verilerin hesaplanması amaçlanmaktadır (Cabrera et al., 2020).

Hayvan Davranışları ve Hayvan Refahı

Hassas hayvancılık uygulamalarının hayvan refahı izleme sistemleri, hayvan temelli göstergeleri puanlayan uzmanlar tarafından hayvan refahını değerlendirmeye yönelik kullanılan diğer yaklaşımlardan temel olarak farklıdır. Hayvan yetiştirilirken bir sorunu tespit etmek, derhal yönetim önlemini almak ve hayvanın yaşam standartlarını iyileştirmek çok iyidir. Hassas hayvancılığın amacı da, çiftlikte bir şeyler ters giderken gerçek zamanlı uyarı sağlamak ve böylece çiftçinin sorunu çözmek için derhal harekete geçebilmesini sağlamaktır (Berckmans, 2017).

Hayvan refahı, hayvan sağlığının bir parçası olup, hayvan davranışları da hayvan refahının en önemli göstergesidir. (Berckmans, 2017). Hayvan refahını belirlerken yeme, içme, hastalık ve östrus tespiti gibi davranışları dikkate almak gerekmektedir. Sığır ve buzağılarda, görüntü ve sensör tabanlı teknolojiler kullanılarak, hayvanların beslenme ve yatma davranışı verileri referans alınarak, hayvan aktivitelerini izlemeye ve hayvan refahını belirlemeye yönelik ticari sistemler geliştirilmiştir. Bu amaçla, çeşitli sensörlerden gelen verileri etkili bir şekilde birleştirebilen, bireysel bir hayvanın refahının veya sürü düzeyinde refahın doğru bir temsilini oluşturabilen bir dizi uygulama oluşturulmaktadır (Cockburn, 2020; Schillings et al., 2021; Morrone et al. 2022). Örneğin; geviş getiren hayvanlar için geliştirilmiş ivmeölçerler, hayvanların vücutlarına bağlanarak hayvanların bireysel yatma, ayakta durma veya yürüme gibi davranışları, konumları veya duruşları izlenebilmektedir (Cockburn, 2020; Schillings et al., 2021; Neethirajan and Kemp, 2021). Sığırlarda agonistik davranışların yanı sıra hayvanların sosyal etkileşimleri ve annelik davranışlarını tespit etmek için geliştirilmiş bazı teknolojiler ise henüz erken gelişim aşamalarındadırlar. Özellikle agonistik davranışların izlemesi, hayvanlar arasındaki sosyal ilişkilerin (baskınlık gibi) belirlenmesi, hayvanların çevresinden nasıl etkilendiğinin daha iyi anlaşılmasını sağlayabilmektedir (Schillings et al., 2021). Ayrıca, hayvanların otlatma sırasında davranışlarının belirlenmesi amacıyla, sensörlerin kurulumunu ve meraya dayalı süt sığırcılığında da ahır dışındaki hayvanların otlama, yürüme ve dinlenme davranışlarına bilgileri makine öğrenme destekli küresel konumlandırma sistemi (GPS) aracılığıyla verilerinden zamansal konumlandırma yoluyla ayırt edebilen davranışsal modellerde kullanılmaktadır (Cockburn, 2020). Yine yapay zekanın alt teknolojileri sayesinde, yetiştiriciler, hayvanlarının sosyal gruplarını ve duygu durumlarını veya onların fizyolojik parametrelerini sürekli olarak izleme fırsatı bulmaktadır (Cockburn, 2020).

Biyo-geribildirim sistemleri aracılığıyla toplanan sensör verilerinden çiftlik hayvanlarının dinamik olarak değişen yüz ifadesi özelliklerine ilişkin gerçekçi görüntü ve video dizileri (giyilebilir sensörler ve kamera tabanlı görüntüler) oluşturmaya yönelik bir yaklaşım ile çiftlik hayvanlarının duygularını tahmin etme ve sınıflandırmayı sağlayan sistemlerde bulunmaktadır (Neethirajan and Kemp, 2021; Goller et al., 2021). Üretken çekişmeli ağların makine öğrenme algoritmaları kullanılarak, hayvanların sanal, dijital bir ikizinin geliştirildiği sistemler sayesinde, gerçek zamanlı, 3 boyutlu hayvan yüzlerinin oluşturulduğu, sanal modeller hayvanların kulak ve göz hareketlerini

inceleyerek hayvan davranışını daha iyi tahmin edebilmekte ve hayvanın stresi, ağrı ve hastalığın erken belirtileri tespit edilebilmektedir (Neethirajan and Kemp, 2021).
Sensör teknolojilerinin kullanıldığı bazı örnekler; hayvanların kızılötesi radyasyon seviyelerini yakalayarak vücut sıcaklıklarını ölçebilen termal kızılötesi sensörleri; göğüs ve karın hareketlerini ölçmek için tipik olarak göğsün etrafında bir kemerden oluşan solunum hızı sensörleri; hayvan biyolojik sıvılarındaki kortizol ve laktat gibi hormonların değerlendirilmesini sağlamak için tükürük ve ter üzerinde çalışabilen immünosensörleri; fotopletismografi (PPG), dokunun mikrovasküler yatağındaki kan hacmindeki değişiklikleri tespit etmek için kızılötesi ışıklar kullanılması ve büyük hayvan sürülerinin su içme davranışlarını izlemede kullanılan su akış sensörleri olarak sıralanabilmektedir (Neethirajan and Kemp, 2021). Sensör teknolojileri kullanılarak çiftlik hayvanlarının nakliye sırasında konforunun ve refahının gerçek zamanlı olarak ölçülebilmesi sayesinde, hayvan refahı önemli ölçüde iyileştirilebilir ve böylece hayvan taşımacılığı için daha iyi sürdürülebilir koşullar geliştirilebilmektedir (Neethirajan and Kemp, 2021).

Sonuç

Hayvancılık sektöründe, Hassas Hayvancılık (Hayvancılık 4.0) tabanlı teknolojilerin kullanımı büyük bir dönüm noktası olmuştur. Teknolojinin sürekli olarak gelişmesi ve yaygınlaşması çiftçilerin daha ucuz ve etkili cihazlara sahip olmalarına olanak sağlayabileceği gibi hassas hayvancılık teknolojilerinin işletmelerine daha kolay uyarlamalarına fırsat sunacaktır. Küreselleşen dünyada, hayvansal gıda ürünlerine yönelik katlanarak artan talebin bir sonucu olarak bu teknolojilerin çiftliklerde yaygınlaşmasının kaçınılmaz olacağı ön görülmektedir. Hassas Hayvancılık (Hayvancılık 4.0) teknolojilerin kullanımının artması, hayvancılığın daha verimli hale gelmesini sağlamakla birlikte, bu alanda giderek artan sayıda araştırma ve daha yeni çalışmalarının yürütülmesini teşvik etmektedir. Hassas Hayvancılık (Hayvancılık 4.0) teknolojileri, modern hayvancılığın ayrılmaz bir parçası haline gelmektedir. Çiftliklerde, mikroişlemciler, dronlar, görüntüleme, hücresel iletişim, bulut sistemleri, nesnelerin interneti, yapay zeka, büyük veri gibi yeni teknolojilerin yazılım, donanım, robot, cihaz, sensör ve akıllı makineler aracılığıyla anlık olarak hayvan sağlığı ve refahının izlemesi, standartlarının oluşturulması, büyük verinin etkin bir şekilde yönetilmesi ve çevresel olarak sürdürülebilir ekipmanların geliştirilmesi, bu teknolojinin gelecekte çiftliklerde verim ve sürdürülebilirlik sağlamak için daha iyi bir potansiyele sahip olabileceği düşünülmektedir.

Kaynaklar

Kraft, M., Bernhardt, H., Brunsch, R., Büscher, W., Colangelo, E., Graf, H., Marquering, J., Tapken, H., Toppel, K., & Westerkamp, C., et al. (2022). Can Livestock Farming Benefit from Industry 4.0 Technology? Evidence from Recent Study. Applied Sciences. 12(24):12844. https://doi.org/10.3390/app122412844

Morrone, S., Dimauro, C., Gambella, F., & Cappai, M.G. (2022). Industry 4.0 and Precision Livestock Farming (PLF): An up to Date Overview across Animal Productions. Sensors. 22(12):4319. https://doi.org/10.3390/s22124319

Goller, M., Caruso, C., & Harteis, C. (2021). Digitalisation in agriculture: knowledge and learning requirements of German dairy farmers - In: International journal for research in vocational education and training 8(2):208-223 - URN: urn:nbn:de:0111-pedocs-233236 - DOI: 10.25656/01:23323

Yaman, H., Sungur, O., & Dulupçu, M.A. (2021). Dünyada Tarım ve Hayvancılığın Dönüşümü: Teknolojiye Dayalı Uygulamalar ve Devrimler. Tarım Ekonomisi Dergisi, 27(1):123-133, DOI 10.24181/tarekoder.938925

Van Hertem, T., Bahr, C., Schlageter, Tello, A., Viazzi, S., Steensels, M., Romanini, C.E., Lokhorst, C., Maltz, E., Halachmi, I., & Berckmans, D. (2016). Lameness detection in dairy cattle: single predictor v. multivariate analysis of image-based posture processing and behaviour and performance sensing. Animal. Sep;10(9): 1525-32. doi: 10.1017/S1751731115001457. Epub 2015 Aug 3. PMID: 26234298.

Carpentier, L., Berckmans, D., Youssef, A., Berckmans, D., van Waterschoot, T., Johnston, D., Ferguson, N, Earley, B, Fontana, I., Tullo, E., Guarino, M, Vranken, E., & Norton, T. (2018). Automatic cough detection for bovine respiratory disease in a calf house. Biosystems Engineering, 173: 45-56, ISSN 1537-5110, https://doi.org/10.1016/j.biosystemseng.2018.06.018.

Lowe, G., Sutherland, M., Waas, J., Schaefer, A., Cox, N., & Stewart, M. (2019). Infrared Thermography—A Non-Invasive Method of Measuring Respiration Rate in Calves. Animals. 9(8): 535. https://doi.org/10.3390/ani9080535

Schillings, J., Bennett, R., & Rose, D.C. (2021). Exploring the Potential of Precision Livestock Farming Technologies to Help Address Farm Animal Welfare. Front. Anim. Sci. 2:639678. doi: 10.3389/fanim.2021.639678

Waiblinger, S., Boivin, X., Pedersen, V., Tosi, M., Janczak, A.M., Visser, E.K., & Jones, R.B. (2006). Assessing the human–animal relationship in farmed species: A critical review. Applied Animal Behaviour Science. 101,185–242.

Cabrera, V.E., Barrientos-Blanco, J.A., Delgado, H., & Fadul-Pacheco, L. (2020). Symposium review: Real-time continuous decision making using big data on dairy farms, Journal of Dairy Science. 103 (4); 3856-3866 ISSN 0022-0302, https://doi.org/10.3168/jds.2019-17145.

Cockburn, M. (2020). Review: Application and Prospective Discussion of Machine Learning for the Management of Dairy Farms. Animals. 10(9):1690. https://doi.org/10.3390/ani10091690

Jo, S.K., Park, D.H., Park, H., & Kim, S.H. (2018). Smart Livestock Farms Using Digital Twin: Feasibility Study. 2018 International Conference on Information and Communication Technology Convergence (ICTC), Jeju, Korea (South) , pp. 1461-1463, doi: 10.1109/ICTC.2018.8539516.

Vázquez-López, A., Barrasa-Rioja, M., & Marey-Perez, M. (2021). ICT in Rural Areas from the Perspective of Dairy Farming: A Systematic Review. Future Internet, 13, 99. https://doi.org/10.3390/fi13040099

Neethirajan, S., & Kemp, B. (2021). Digital Twins in Livestock Farming. Animals. 11(4): 1008. https://doi.org/10.3390/ani11041008

Berckmans, D. (2017). General introduction to precision livestock farming. Animal Frontiers, 7(1):6–11, https://doi.org/10.2527/af.2017.0102

Norton, T., & Berckmans, D. (2017). Developing precision livestock farming tools for precision dairy farming, Animal Frontiers, Volume 7(1): January, 18–23, https://doi.org/10.2527/af.2017.0104

Kang, X., Zhang, X.D., & Liu, G. (2020). Accurate detection of lameness in dairy cattle with computer vision: A new and individualized detection strategy based on the analysis of the supporting phase. J. Dairy Sci. 103:10628–10638 https://doi.org/10.3168/jds.2020-18288

Tuvay, N.H., & Ermetin, O. (2023). Yapay zekâ teknolojilerinin hayvancılıkta kullanımı. Hayvansal Üretim 64(1): 48-58. https://doi.org/10.2918 5/hayuretim.1034328

Ermetin O. (2023). Evaluation of the application opportunities of precision livestock farming (PLF) for water buffalo (Bubalus bubalis) breeding: SWOT analysis. Arch. Anim. Breed., 66, 41–50, https://doi.org/10.5194/aab-66-41-2023

Smart Packaging Technologies

Özlem Erol[1], İlknur Uçak[2]

[1] Department of Animal Production and Technologies, Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University, Nigde, Turkey
[2] Department of Animal Production and Technologies, Faculty of Agricultural Sciences and Technologies , Niğde Ömer Halisdemir University, Nigde, Turkey

Abstract

The time period from the production of food products to the logistics and quality management processes that extend to the final consumption point is of critical importance in terms of preserving the freshness and nutritional value of the product. For this reason, many food preservation methods have been used from the past to the present. With the developing technology, increasing consumer awareness has also been reflected in product packaging, and importance has begun to be given to issues such as providing functional features to packages, minimizing food waste, and developing environmentally compatible materials. In this context, modern packaging methods have been developed and started to be used. Smart packaging is the newest packaging system that draws attention with its innovative features in the sector. In addition, smart packaging systems are an innovative approach that contributes to reducing waste on a global scale in line with food safety and sustainability goals. This review aims to provide information about smart packaging methods and their related applications.

Key Words: *Smart Packaging, Food Safety, Consumer Safety*

Introduction

Packaging in the food industry is a type of protection system that prevents contamination of food products with unwanted microorganisms and provides product preservation during product logistics and all subsequent stages, as well as containing information about the product (Otles and Sahyar, 2016; Drago et al., 2020). The main goal of food packaging is to protect the safety and nutritional value of food from production to the consumer (Cutter, 2006). In addition, it is aimed to minimize food loss and waste that may occur in the process, to have a positive effect on consumer health by using less food preservative additives and to ensure that the consumer is satisfied with the product (Inamuddin et al., 2023).Smart packaging systems are divided into two main categories according to their functional mechanisms: active packaging and smart packaging. While smart packaging is divided into three groups: sensors, indicators and data carriers, active packaging is divided into two groups: retaining materials and releasing materials (Vasuki et al., 2023).

Smart packaging is a system designed to provide information about the food product to the consumer and has two types: those that show the external conditions of the packaging and those that directly measure the quality of the food product. Smart packaging devices are labels or receipts that are added to the inside or outside of the product packaging or printed on the packaging material (Dainellia et al., 2008). It varies not only in physical context but also in the amount and type of information it can carry and how it receives and distributes this information. Multiple smart components can be integrated simultaneously onto packages (Yam et al., 2005). This review aims to provide information about smart packaging technology systems used in meat and meat products.

Smart Packaging

Smart packaging includes systems that are combined with food packaging material or work with the principle of labeling on food. It is aimed to provide more comprehensive information to the consumer by monitoring product quality and critical points throughout the supply chain (Han and Rodrigues, 2005). In smart packaging, various systems are generally used, including indicators, barcodes, radio frequency identification labels and sensors (Akkemik and Güner, 2020).

Indicators

The indicators used in smart packaging are divided into three groups: leakage, freshness and temperature-time indicators. Leakage indicators are systems that monitor the presence of certain gases in the environment and provide information about the integrity of the food product's packaging and possible leaks. There are two types of leakage indicators, oxygen and carbon dioxide indicators, and their working principle is that they cause a color change in the presence of chemical and enzymatic reactions when placed inside the packaging (Yezza, 2008; Özçandır and Yetim, 2010).

The main purpose of freshness indicators is to detect product losses that occur due to reactions that may occur in the food during the shelf life of the food product in its physical and chemical properties. Freshness indicators that are sensitive to pH, volatile nitrogenous compounds, hydrogen sulfide and microbial metabolites can be given to the freshness indicators used in recent years (Üçüncü, 2011). Finally, when looking at temperature-time indicators, it is a small measurement tool that provides visual information about the temperature history of food throughout the distribution chain (Purma and Serdaroğlu, 2006). It is primarily preferred in perishable foods such as fish, dairy products, meat, poultry, frozen fruits and vegetables, and frozen meats (Kocaman and Sarımehmetoğlu, 2010). Table 1. Commonly used indicators, their working principles, the information they provide, and their application areas are given (Kaur and Puri, 2017).

Indicators	Principle/Reactants	Information Provided to Consumer	Application
Time-temperature indicators (External)	Mechanical Chemical Enzymatic	Storage condition	Foods stored under refrigerated and frozen conditions
Oxygen indicators (Internal)	Redox dyes pH dyes Enzymes	Storage condition Package leakage	Foods stored in low-oxygen concentration packages
Carbon dioxide indicators (Internal)	Chemical	Storage condition Package leakage	Modified or controlled atmosphere food packaging
Microbial growth or Freshness indicators (Internal/External)	pH dyes Dyes that react with specific metabolites (volatile or non-volatile)	Spoilage (Microbial food quality)	Perishable foods such as meat, fish, and poultry
Pathogen indicators (Internal)	Dyes that react with toxins Various chemical and immunochemical methods	Specific pathogenic bacteria such as Escherichia coli O157:H7	Perishable foods such as meat, fish, and poultry

Table 1. Some commonly used indicators (Kaur and Puri, 2017)

Barcodes

It is the cheapest and most commonly used information carrier used to introduce the product or material. Information about the product consists of a linear symbol, a line and a field, and is expressed with 12 digits. Due to the limited data storage volume of Universal Product Code (UPC) barcodes, existing data has been optimized with RSS (Reduced Space Symbology) barcodes, which allow more product information to be effectively included in smaller areas, 2-dimensional barcodes such as Portable Information File (PDF) - 417, and barcodes called "composite symbol", where linear barcode and 2-dimensional barcode are used together (Yam, 2000; Yam et al., 2005). As a result of this optimization, various data entry options such as nutritional value, cooking recommendations, and the manufacturer's web address, which are impossible to achieve with one-dimensional barcodes, are made possible (Yam, 2000). Barcodes also provide heating options according to the type of food product, save labor by preventing manual entry of heating commands, and provide convenience for people with vision problems or difficulty understanding languages (Yam, 2000). Figure 1. Examples of some barcode applications are given (Anonymous, 2021).

Figure 1. Some Barcode Applications (Anonymous, 2021)

Radio Frequency Identification (RFID) Tags

RFID, which allows wireless information transfer, is a system that plays a role in automatic product recognition and traceability. Recently, it has been used in packaging (Yam et al., 2005). The main elements of the system are; tag, antenna, reader, interrogator and controller (Yuksel and Zaim, 2009). While it is divided into two parts as active and passive tags according to the power source used, semi-passive tags have also been added recently. Passive tags are activated by the reader and have a reading distance of up to 4.5 meters. The difference between active tags and passive tags is that active tags have their own battery and generate their own energy and send signals to the reader. The reading distance of active tags is 30 meters and more (Angeles, 2005; Yam et al., 2005). The operating principle of the system is based on the fact that information and energy transfer occurs between the RFID tag and the reader without contact. The electromagnetic waves emitted by the reader are transmitted to the antenna on the tag, providing interaction and activating the circuits in the microchip to operate the system. The microchip regulates the waves and gives feedback to the reader, and the reader creates digital data and transmits it to a computer with an internet or network connection (Angeles, 2005). Using these labels provides benefits such as taking precautions against problems that may occur during the production and distribution process, ensuring that products are positioned regularly and strategically in the warehouse and distribution processes, thus enabling easy product sales transactions, minimizing product entry and exit traffic control times, actively monitoring the expiration date, reducing labor costs, improving customer experience and increasing service quality (Angeles, 2005). The success of RFID tag usage can be achieved by the design of this system and the adoption of the application by all actors in the supply chain and their integration into their processes (Kelepouris et al., 2007). It is stated that the world's leading retail companies such as WalMart, Marks & Spencer, Chevrolet Creative, FedEx, and Metro Future Store use these tags (Angeles, 2005).

Sensors

Gas sensors are systems that help maintain the quality and safety of food by providing information about the amount of gas in the package and/or in the environment. The content of the gas to be placed in the package changes frequently as a result of the activity of the food product or leaks in the packages, depending on the nature of the package and the environmental conditions of the package (Yam et al., 2005). These changes are usually detected using oxygen and carbon dioxide indicators, and leakage/leakage indicators in package integrity checks. Indicators are in direct contact with the food inside the package (De Jong et al., 2005).

The working principle of biosensors, which are mostly used in smart packaging as toxin indicators, is that toxin indicators have a specific effect on the toxin found in a single microorganism. The critical difficulty that arises during the use of these indicators is that pathogenic microorganisms are mostly found in low amounts inside or on the surface of food and pose a health risk even at these low concentrations, and in addition, they are not distributed evenly within the food. Therefore, the sensor to be used must be highly sensitive and have maximum contact with the food (De Jong et al., 2005). In order to detect the presence of pathogens, SIRA Technology (USA) has developed a biosensor/barcode combination called ‘Food Sentinel System’ for food packages, which is shaped according to the principles of immunochemical reactions (Yam et al., 2005; Zeuthen and Bogh-sorensen, 2003).

Results and Discussion

Smart food packaging technology has the function of providing information to the consumer, extending the shelf life of food products by protecting them against microbial contamination, maintaining quality stability and maximizing safety. Therefore, smart packaging, which has been developed and used within modern packaging methods, has many advantages for both the consumer and the producer. The increasing number of studies on this subject in recent years provides information about the topicality of the subject.

References

Akkemik, Y., & Güner, A. (2020). Gıda ambalaj sistemlerinde yeni yaklaşımlar: Akıllı ambalaj sistemleri. *Türk Bilimsel Derlemeler Dergisi*, *13*(1), 9–22. https://dergipark.org.tr/tr/pub/tubid

Angeles, R. (2005). RFID technologies: Supply chain applications and implementation issues. *Information Systems Management*, *22*(1), 51–65. https://doi.org/10.1201/1078.10580530/45532.22.1.20051201/91169.7

Anonim. (2021). The indicator. Tempix. https://www.tempix.com/the-indicator (Erişim tarihi: 01.09.2021).

Cutter, C. N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Science*, *74*, 131–142. https://doi.org/10.1016/j.meatsci.2006.04.023

Dainelli, D., Gontard, N., Spyropoulos, D., Beukend, E. Z., & Tobback, P. (2008). Active and intelligent food packaging: Legal aspects and safety concerns. *Trends in Food Science & Technology*, *19*(S1), S103–S112. https://doi.org/10.1016/j.tifs.2008.09.011

De Jong, A. R., Boumans, H., Slaghek, T., Van Veen, J., Rijk, R., & Van Zandvoort, M. (2005). Active and intelligent packaging for food: Is it the future? *Food Additives and Contaminants*, *22*(10), 975–979. https://doi.org/10.1080/02652030500239697

Drago, E., Campardelli, R., Pettinato, M., & Perego, P. (2020). Innovations in smart packaging concepts for food: An extensive review. *Foods*, *9*(11), 1628. https://doi.org/10.3390/foods9111628

Han, J., Ho, C., & Rodrigues, E. (2005). Intelligent packaging. In J. H. Han (Ed.), *Innovations in food packaging* (pp. 138–155). Elsevier.

Inamuddin, Altalhi, T., & Cruz, J. N. (2023). Methods for producing smart packaging. In *Green Sustainable Process for Chemical and Environmental Engineering and Science* (p. 262). Elsevier. https://doi.org/10.1016/C2021-0-03315-0

Kaur, S., & Puri, D. (2017). Active and intelligent packaging: A boon to food packaging. *International Journal of Food Science and Nutrition*, *2*, 15–18.

Kelepouris, T., Pramatari, K., & Doukidis, G. (2007). RFID-enabled traceability in the food supply chain. *Industrial Management & Data Systems*, *107*(2), 183–200. https://doi.org/10.1108/02635570710723731

Kocaman, N., & Sarımehmetoğlu, B. (2010). Gıdalarda akıllı ambalaj kullanımı. *Veteriner Hekimler Derneği Dergisi*, *81*(2), 67–72.

Otles, S., & Sahyar, B. Y. (2016). Intelligent food packaging. In V. Scognamiglio, G. Rea, F. Arduini, & G. Palleschi (Eds.), *Comprehensive Analytical Chemistry* (Vol. 74, pp. 377–387). Elsevier. https://doi.org/10.1016/bs.coac.2016.04.010

Özçandır, S., & Yetim, H. (2010). Akıllı ambalajlama teknolojisi ve gıdalarda izlenebilirlik. *Gıda Teknolojileri Elektronik Dergisi*, *5*(1), 1–11.

Purma, Ç., & Serdaroğlu, M. (2006). Akıllı ambalajlama sistemlerinin gıda sanayinde kullanımı. In *Türkiye 9. Gıda Kongresi* (24–26 Mayıs, Bolu).

Üçüncü, M. (2011). *Gıda ambalajlanma teknolojisi*. Ambalaj Sanayicileri Derneği.

Vasuki, M. T., Kadirvel, V., & Narayana, G. P. (2023). Smart packaging—An overview of concepts and applications in various food industries. *Food Bioengineering*, *2*(1), 25–41. https://doi.org/10.1002/fbe2.12038

Yam, K. L. (2000). Intelligent packaging for the future smart kitchen. *Packaging Technology and Science*, *13*, 83–85.

Yam, K. L., Paul, T., & Miltz, J. (2005). Intelligent packaging: Concepts and applications. *Journal of Food Science*, *70*(1), R1–R9.

Yezza, I. A. (2008). Active/intelligent packaging: Concept, applications and innovations. In *Technical Symposium: New Packaging Technologies to Improve and Maintain Food Safety* (18–19 September, Toronto).

Yüksel, M. E., & Zaim, A. H. (2009). Yeni nesil teknoloji olarak RFID, RFID sistem yapıları ve bir RFID sistem tasarımı yaklaşımı. In *5. Uluslararası İleri Teknolojiler Sempozyumu (IATS'09)* (13–15 Mayıs, Karabük, Türkiye).

Zeuthen, P., & Bøgh-Sørensen, L. (2003). Monitoring the effectiveness of food preservation. In P. Zeuthen & L. Bøgh-Sørensen (Eds.), *Food Preservation Techniques* (pp. 553–565). CRC Press/Woodhead Publishing.

Smart Livestock Applications

Özlem Erol[1], İlknur Uçak[2]

[1] Department of Animal Production and Technologies, Faculty of Agricultural Sciences and Technologies , Niğde Omer Halisdemir University, Nigde, Turkey
[2] Department of Animal Production and Technologies, Faculty of Agricultural Sciences and Technologies , Niğde Ömer Halisdemir University, Nigde, Turkey

Abstract

Along with the increasing population, the issue of sustainability has come to the forefront, and maximum product efficiency requires the use of traditional systems in the livestock sector to be replaced with systems compatible with technology. Therefore, the use and development of technological applications play a critical role in the advancement of livestock. The rapid development of technology also provides various advantages such as the advancement of computer software and systems, which in turn meet the demands and needs of breeders, as well as monitoring the work done in livestock and increasing animal welfare and efficiency as a result of making decisions with minimum errors. In this review, the importance and necessity of the use of technology in the livestock sector will be discussed, and information will be provided about animal identification, global positioning system, milking automation, feeding automation, pedometer (pedometer), and animal health monitoring systems from Industry 4.0 applications.

Key Words: *Importance of Technology Use in Animal Husbandry, Industry 4.0 Applications, Smart Livestock Applications*

Introduction

Global warming, climate change, increasing population and changes in demand and supply are accelerating the orientation and meaning of the agriculture and livestock sector. The recent Covd-19 outbreak, which has had a wide impact all over the world, has shown that agriculture and livestock have more importance in our lives than thought. As a result of the difficulties experienced, it has paved the way for studies on how effectively countries can use developing technology in addition to product production in agriculture and livestock (Yaman et al., 2021).

Economically valuable agriculture and animal husbandry have gone through various development processes from past to present, and this process continues to gain momentum. Transformations and developments experienced since primitive times have occurred within the framework of technology (Yaman et al., 2021). In this respect, there are many advantages offered by smart systems that are widely used today. Utilizing technologies in milking, nutrition, environmental control, reproductive performance and farm management is important in terms of minimizing human errors and increasing productivity, as well as maintaining economic and sustainability throughout the entire process (Gökçe et al., 2020). Advances and technological changes experienced on an international scale show that the use of technology in agriculture and animal husbandry will gradually increase in the future (Yaman et al., 2021).

The Importance and Necessity of Using Technology in Animal Husbandry

The agricultural and livestock sector, which is economically important, has undergone significant changes and developments since its inception and continues to develop. It is seen that global developments and technological advances in the agricultural and livestock sector are becoming increasingly important with the impact of industrialization. The rapid development of technology provides significant contributions to the implementation of computer software and systems. This is also reflected in animal husbandry, and the technological tools produced provide convenience to producers and create an opportunity to increase animal productivity and sustainability. Many technological tools have made animal husbandry more practical and easier. For example, in herd management, the applications that need to be done daily are structured according to the accuracy of the records. At this point, smart systems offer farmers many opportunities. Feeding, environmental control, reproductive performance and milking constitute the daily tasks in animal husbandry that are most affected by correct production decisions. Human errors and decisions that may occur at these stages should not be risked, as they have a great impact on the quality of the product and economic benefit (Yaman et al., 2021).

The increasing population requires the highest level of product efficiency in animal husbandry, therefore, intensive and purposeful system use should be provided in controlled production areas. In response to the increasing demand for animal products in developing countries, there are increases in the number of large-scale animal production areas and units. (van't Hooft et al., 2012). It is expected that the global demand for animal foods will increase by 70% by 2050. This global increase should be met in a way that will have the least impact on the environment (McFarlane, 2019). This situation necessitates the use of more technological and sustainable systems instead of traditional systems used in the animal husbandry sector. In this context, technological developments in the animal and plant agriculture sector include the use of many tools, methods and techniques that are used to increase performance and include advanced technology (Yaman et al., 2021).

New technology-based techniques and methods are frequently used in the animal and plant agriculture sector in the world. In this context, many production methods that are carried out in different ways using new and technological methods in the agricultural sector stand out. For example, genetic applications are frequently used to increase performance and efficiency. These applications, which pave the way for a sustainable future for animal husbandry, increase animal welfare and productivity (McFarlane, 2019). These breeding studies aim to increase animals that are more resistant to diseases, have high yield performance, and have high welfare and health. The main technologies that meet the demands of breeders are electronic records, heat detection, feeding, milking and health records. Some sensors are currently suitable for this purpose, but they cannot meet all demands (Gökçe et al., 2020).

Industry 4.0 in Animal Husbandry

Industry 4.0, which provides the integration of information and communication technologies (ICT) and industry, has begun to implement applications aimed at integrating information technologies with animal husbandry based on the basic approach (Gökçe et al., 2020). In the online system, by creating rations optimized with feed raw materials according to the production potential of animals, increasing nutritional efficiency, determining estrus for reproductive performance and creating an insemination program, and ensuring traceability, quality and reliable food production and sustainability in order to increase efficiency at all stages, the use of information technology in animal husbandry is becoming widespread over time. Technologies that respond to the demands and needs of breeders are electronic records, milking, estrus detection, nutrition, barn environment optimization and health records. Although specific sensor hardware is considered sufficient in terms of use of the existing sensor infrastructure, it is insufficient to meet all demands due to performance limits (Akay, 2018).

Identification of Animals

Animal identification, which is a system used to track and monitor animals, is done for various reasons in animal and farm related issues such as biosecurity management, keeping records of the obtained data, and proper farm management for maximum productivity gain.

Identification is of great importance in controlling the performance status of the animal as well as the yields of the animal in animal production. Therefore, proper and accurate animal identification will ensure record keeping and improvement of herd management in the light of the information obtained. The problem encountered in farms has been to obtain symbols and codes that are different and cannot be lost, recognizable and identifiable by everyone. Automatic identification in animal breeding mostly consists of two different systems. The first system is the transponder system and its purpose is to recognize the animal within the control system. A fixed antenna is used in a stall (milking stand and feeding station) or along the corridor (automatic weighing or milking stand) such as the electronic reader shown in Figure 1. The purpose of the second system is to control the health of the animal and to ensure that the process related to the reproductive performance is recorded. Here, the system only has the functions of receiving, recording and displaying the animal's ID code. This system allows the animal to be identified safely and the code to be identified reliably. It also eliminates possible risks and difficulties. Portable antenna transponders are generally used in this system. It is used especially in the breeding of pigs and small ruminants (Panchal et al., 2019). The ‘Radio Frequency Identification System’ (RFID), whose working principle diagram is given in Figure 2, is used in the observation and identification of animals.

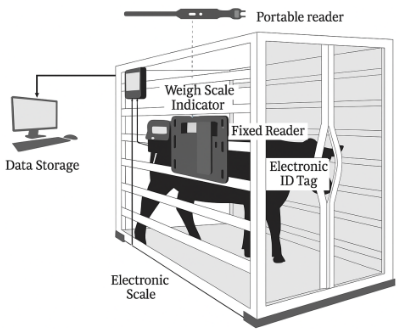


Figure 1.Electronic reader (Anonymous, 2019a).

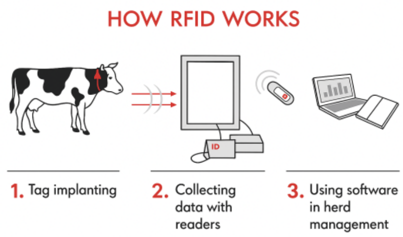


Figure 2. RFID system (Gökçe ve ark., 2020)

Global Positioning System

The Global Positioning System, also known as GPS, is defined as a space-based satellite navigation system that contains all location and time information. GPS transmits radio signals by systems based on latitude, longitude and altitude (Panchal et al., 2019). GPS helps farmers in the use of tractors, increases performance, reduces production risk and does not harm the environment. In animal husbandry, it can control feed consumption (Husti et al., 2017).

Milking Automation

Automatic milking systems are generally referred to as automatic milking systems or voluntary milking systems in dairy farming. Milking is a set of tasks that require balanced milking intervals to remove milk from the udder and maintain milk yield and performance during the lactation period. The milking process is divided into various tasks such as directing the animals to the milking parlor before milking, examining and cleaning the teats of the animals, checking and examining some characteristics of the milk, removing the milking equipment, and taking the animal out of the milking parlor. Modern and technological milking systems have the infrastructure that supports the conductivity of the milk, the temperature of the milk, the color of the milk, the change in the speed and duration of milking, the amount of milk secreted from the cow, the movements of the cow and the time spent in rumination.

In traditional systems, cows are milked twice a day. They line up and wait during milking, which causes stress in the cows. In voluntary milking systems, animals enter milking whenever they want. Cows are encouraged to milk in the milking automation system with both the presence of feed and the stimulations made to the udder. Thanks to electronic tagging, automation can take one cow before another, and thanks to smart doors, priority can be given to only this cow. Automatic brushes clean the udder, and then the pumps are carefully placed in the udder with a robotic arm using positioning sensors. Other sensors control and monitor the milk flow in the animal's udder lobes, so the animal is neither milked too little nor too much. At the end of milking, the cow's udders are cleaned again, while the milk is drained into a tank, filtered, and cooled (Anonymous, 2019b). Figure 3.The milking phase of the cow in the robotic milking system is given (Alıç and Yener, 2006).

Figure 3. Milking process in robotic milking system

Feeding Automation

Since feed costs are the main source of expenditure in the livestock sector, reducing feed costs by a minimum can lead to significant improvements in the profits of enterprises. In this process, feed preparation machines, feed mixers and distributors that make sensitive measurements in feed preparation are frequently used technological applications. The working principle of automatic feed systems is based on the integration of feed units and automatic recognition system and the control of the obtained information by means of software loaded on a computer (Boğa et al. 2008; Göncü et al. 2015).

In the software used, the daily feed consumption amount and frequency of animals are determined by taking into account the demands of the users, and in addition, it is used to determine the amount of feed not consumed by the animal from the total daily feed amount determined (Spahr, 1989). Here, while the determined animals come to the feeders containing automatic sensitive weighing scales and eat the feed, records are kept of information such as how much feed the animals eat in how long and when the feed comes. The information recorded in the feeders in minute intervals is automatically sent to the central system via wireless systems (Herd et al. 2003). Figure 4. The automatic feeding machine located in Niğde Ömer Halisdemir University Ayhan Şahenk Agricultural Application and Research Center is given.

Figure 4. Automatic feeding system giving feed to animals

Pedometer

Estrus is the period of time when a cow, under normal conditions, allows the bull to mate or becomes pregnant when inseminated. The device that monitors the animal continuously checks and observes the body temperature of a cow, indicating whether estrus has started and when the most suitable time for artificial insemination (Panchal et al., 2019; Gündüz and Akyüz, 2017). Figure 5. The pedometer used for estrus detection is shown (Gündüz and Akyüz, 2017).

Figure 5. Pedometer (Gündüz and Akyüz, 2017)

Animal Health Monitoring Systems

The traceability of animals throughout their lives is of great importance for the protection of animal health, disease prevention and food safety. Animal Health Tracking Systems developed for this purpose help to monitor and digitally record the identity, health and movements of animals (Demir & Aksoy, 2018). Thanks to this system, examinations, vaccinations and disease control diagnoses can be made more easily throughout the life of animals (Kaya et al., 2020). At the same time, disease detection of animals can be done earlier and they can be brought under control (Ministry of Agriculture and Forestry, 2021).

One of the common systems used for this purpose in Türkiye is TURKVET. TURKVET is a national system that allows animals to be registered. Thanks to this system, the counting of animals, their movements, birth-death information, health and vaccination records can be tracked (Ministry of Agriculture and Forestry, 2021). With the development of technology, Electronic Identification (EID) systems and mobile herd management systems are also increasing. These applications allow individual tracking of animals within the herd by using technology thanks to microchips or RFID (Radio Frequency Identification) and ear tags (Yıldız & Karagül, 2017). In this way, both herd health and epidemiological control can be achieved by individual tracking.

Animal health monitoring systems are of critical importance not only in the animal agriculture sector but also in terms of public health. The detection, control and monitoring of zoonotic diseases become more systematic with these systems (WHO, 2020).

Results

Meeting the ever-increasing population demand in animal husbandry can be achieved by increasing the efficiency and performance of animals. For this purpose, the transformation of traditional systems in use into modern and intelligent systems integrated with technology will play an active role in the advancement of animal husbandry. New systems are added to the systems currently in use in animal husbandry every day and development continues. In this respect, the use of intelligent systems in animal husbandry is important both because it facilitates the work on the farm and increases the welfare of animals in animal production, thus increasing efficiency.

References

Akay, M. (2018). Endüstri 4.0 ile akıllı tarıma geçiş. https://www.researchgate.net/publication/32655078

Alıç, D., & Yener, S. M. (2006). Süt sığırcılığı işletmelerinde robotlu sağım sistemi. Tarım Bilimleri Dergisi, 12(4), 369–380.

Anonim. (2019a). Weighing. https://livestock.trutest.com/enau/weighing (Erişim tarihi: 9 Şubat 2019)

Anonim. (2019b). The innovative techniques in animal husbandry. https://www.intechopen.com/books/animal-husbandry-and-nutrition (Erişim tarihi: 2 Haziran 2019)

Boga, M., Sahinler, S., Gorgulu, M., Kilic, U., Goncu, S., & Cebeci, Z. (2008). Obtaining data for meal criterion for dairy cows in a computerized feeding system. In 4th International Conference on Information and Communication Technologies in Bio and Earth Sciences (HAICTA 2008) (pp. 18–20). Agricultural University of Athens.

Demir, A., & Aksoy, A. (2018). Türkiye'de hayvan kayıt sistemleri ve uygulamaları. Veterinerlik Bilimleri Dergisi, 34(2), 112–120.

Gökçe, G., Göncü, S., & Bozkurt, S. (2020). Endüstri 4.0 ve hayvancılık. Uluslararası Anadolu Ziraat Mühendisliği Bilimleri Dergisi, 3, 21–26. https://doi.org/

Göncü, S., Koluman, N., & Mevliyaoğulları, E. (2015). Entansif süt sığırcılığı işletmelerinde kullanılan sürü yönetim yazılımları karşılaştırması. 9. Ulusal Zootekni Bilim Kongresi, 3–5 Eylül 2015, Konya.

Gündüz, K. A., & Akyüz, E. T. (2017). Nesnelerin interneti ve hayvancılık alanındaki uygulamalar. Journal of Social and Technical Researches, 14, 232–246.

Herd, R. M., Archer, J. A., & Arthur, P. F. (2003). Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. Journal of Animal Science, 81(E-Suppl_1), E9–E17.

Husti, I., Daróczi, M., & Kovács, I. (2017). Messages from "Industry 4.0" to agriculture. In Towards sustainable agricultural and biosystems engineering (pp. 63–79). Universitas-Győr Nonprofit Ltd.

Kaya, G., Yılmaz, T., & Şahin, F. (2020). Hayvan sağlığı bilgi sistemlerinin hayvancılıktaki rolü. Tarım Bilimleri ve Teknolojileri Dergisi, 6(1), 55–61.

McFarlane, G. R., Salvesen, H. A., Sternberg, A., & Lllco, S. G. (2019). On-farm livestock genome editing using cutting edge reproductive technologies. Frontiers in Sustainable Food Systems, 3, 106.

Panchal, S. H., Patel, H. V., Mehta, N., Desai, U., & Jagtap, N. (2019). Survey on use of Industry 4.0 in animal husbandry. Knowledge Journal of Innovation, 1(13), 1.

Spahr, S. L. (1989). New techniques in the mechanization and automation of cattle production systems. In C. J. C. Phillips (Ed.), New techniques in cattle production (Chapter 3). Butterworths.

Tarım ve Orman Bakanlığı. (2021). TÜRKVET hayvan kayıt sistemi rehberi. https://www.tarimorman.gov.tr

Van't Hooft, K. E., Wollen, T. S., & Bhandar, D. P. (2012). Differentiating four livestock production systems. In Sustainable livestock management for poverty alleviation and food security (pp. 36–42).

World Health Organization. (2020). Zoonotic diseases: Emerging public health threats in the 21st century. https://www.who.int

Yaman, H., Sungur, O., & Dulupçu, M. A. (2021). Dünyada tarım ve hayvancılığın dönüşümü: Teknolojiye dayalı uygulamalar ve devrimler. Tarım Ekonomisi Dergisi, 27(1). https://doi.org/10.24181/tarekoder.938925

Yıldız, N., & Karagül, H. (2017). Hayvancılıkta elektronik kimliklendirme ve veri yönetimi. Hayvansal Üretim, 58(3), 1–7.

Vision-Based Artificial Intelligence in Agriculture: Transformer-Based Plant Health and Disease Detection

Cevher Özden[1]

[1]Department of Computer Sciences, Faculty of Arts and Sciences, University of Cukurova, Adana, Turkiye

Abstract

Agricultural productivity is increasingly threatened by plant diseases, leading to significant economic losses and food security concerns. Traditional disease detection methods rely on visual inspections by farmers and experts, which are often time-consuming, labor-intensive, and prone to human error. Recent advancements in artificial intelligence (AI), particularly Transformer-based models, offer a promising solution to enhance the accuracy and efficiency of plant disease identification.

This study explores the application of Vision Transformers (ViTs), Swin Transformer and Convolutional Neural Network for plant health monitoring and disease detection. Unlike traditional Convolutional Neural Networks (CNNs), Transformer-based models excel in capturing long-range dependencies within images, enabling more precise and context-aware predictions. By leveraging large-scale agricultural datasets, these models can learn complex visual patterns associated with various plant diseases.

The research methodology includes data collection from publicly available datasets such as PlantVillage, along with custom-labeled images obtained through drones and mobile devices. The images undergo pre-processing, augmentation, and model training using PyTorch and TensorFlow frameworks. Performance metrics such as accuracy, F1-score, and Intersection over Union (IoU) are used to evaluate the effectiveness of Transformer-based models compared to CNN-based approaches.

Preliminary results indicate that ViTs and Swin Transformers outperform CNNs in detecting plant diseases, demonstrating superior generalization capabilities across different crop types and environmental conditions. This research contributes to the field of precision agriculture by showcasing how AI-driven vision models can revolutionize plant disease management. Future work will focus on Edge AI implementations to enable real-time disease detection on low-power mobile devices and drones. Integrating multimodal data sources, such as hyperspectral imaging and soil health indicators, will further enhance model robustness. The findings emphasize the importance of AI in sustainable agriculture, helping farmers make data-driven decisions and reduce pesticide use while ensuring global food security.

Key Words: *Vision Transformers, Swin Transformer, plant disease detection, artificial intelligence, agriculture*

Introduction

Agricultural productivity is essential for global food security and economic stability. Plant diseases, however, remain a major threat—leading to substantial crop losses and reduced product quality. Traditional disease detection methods that rely on manual visual inspections are labor-intensive, time-consuming, and prone to human error, making them impractical for large-scale farming operations (Toda and Okura, 2019).

Convolutional Neural Networks (CNNs) have been widely adopted for automated plant disease recognition, especially using datasets like PlantVillage. CNN-based approaches, including ResNet and EfficientNet variants, have achieved high accuracy—up to approximately **98–99%**—demonstrating their strong feature extraction ability from plant image (Tugrul et al. 2022). Nonetheless, CNNs' local receptive fields limit their capacity to capture long-range spatial dependencies, which can be critical for distinguishing subtle visual patterns in diseased plant tissues (Li et al. 2023a).

Vision Transformers (ViTs) and their hierarchical variant, the Swin Transformer, present compelling alternatives. ViTs leverage self-attention mechanisms to process images as sequences of patches, facilitating global context modeling. Swin Transformers further enhance this architecture by using shifted-window attention, improving computational efficiency and capturing multi-scale image features—achieving state-of-the-art results on benchmarks such as ImageNet and COCO (Liu et al. 2021).

In agricultural research, ViT-based models have been increasingly applied to plant disease detection. For example, PMVT (a lightweight MobileViT variant) reached accuracy levels of 93–94% across multiple crop datasets (Li et al. 2023b). Additionally, combining ViTs such as ViT, PVT, and Swin in ensemble approaches have shown improved disease classification performance (Bhowmik et al. 2024). Multispectral imaging combined with ViTs also achieved strong detection metrics (test accuracy ~83%, F1 ~89%) using six-band imagery.

PMVT, a lightweight MobileViT variant, employs inverted residuals and attention modules (CBAM) to capture long-range dependencies. It achieves up to 93.6% accuracy on wheat disease datasets, outpacing traditional

MobileNetV3-based models (Li et al. 2023b). TrIncNet, which replaces the MLPs in ViT with Trans-Inception blocks and skip connections, enhances efficiency on PlantVillage and maize images (Gole et al. 2023). PDLC-ViT presents a multitask ViT architecture for simultaneous localization and classification; it attains nearly 99.97% accuracy and high segmentation metrics on PlantVillage (Hemalatha and Jayachandran 2024). Hybrid models like PlantXViT combine CNNs and ViTs (≈0.8 M parameters) to reach above 98 % average accuracy across multiple crop datasets (Thakur et al. 2022). A residual-Swin ensemble (RST-Nets) integrates CNN blocks into Swin to improve robustness, reporting significant accuracy boosts on PlantVillage (Kalpana et al. 2024). ST-CFI fuses convolutional and Swin architectures, achieving 99.94 % accuracy on PlantVillage and strong generalization across other agricultural datasets (Sheng and Lin 2024). Lightweight yet effective variants such as ED-Swin (enhanced with DASPP and EMAGE) demonstrate improvements of ~1–2 % in accuracy and balanced F1 scores on cassava and PlantVillage (Zhang et al. 2025). Multispectral ViTs using visible + NIR bands have reached 83 % accuracy and 89 % F1-score, highlighting the importance of wavelength diversity (De Silva and Brown 2023). Mobile-friendly models, such as MobilePlantViT, combine ViT efficiency and accuracy (80 – 99 %) on edge devices with only ~0.7 M parameters (Tonmoy et al. 2025).

This study empirically compares three architectures—ResNet18 CNN, Vision Transformer, and Swin Transformer—on the PlantVillage dataset, focusing on plant disease identification performance. We additionally explore the use of the Segment Anything Model (SAM) to enhance pixel-level segmentation of infected regions. Through this analysis, our goal is to demonstrate how Transformer-based models can improve detection accuracy, reduce pesticide usage, and support sustainable precision agriculture practices by enabling early and targeted interventions.

Materials and Methods

We utilized the PlantVillage dataset, which contains roughly 54,303 labelled images of healthy and diseased plant leaves across 38 classes. Images were organized via torchvision.datasets.ImageFolder, resized to 224×224 px, normalized (mean=0.5, std=0.5 across RGB channels), and then split into training (80%) and validation (20%) sets using random_split. Batching (size=32) and shuffling were handled via DataLoader. To increase generalization, we applied spatial augmentations, including random crops, flips, and rotations, alongside normalization. These augmentations improve robustness under natural variances such as lighting and leaf orientation, similar to those in previous studies.

Three distinct deep learning architectures were trained and compared:

1.CNN (ResNet-18): A classic convolutional backbone pre-trained on ImageNet, with the final fully-connected layer adapted to match our 38 classes. ResNet variants have demonstrated near-99% accuracy on PlantVillage in multiple studies (Krishna et al. 2025).

2.Vision Transformer (ViT): We adopted a base ViT model (vit_base_patch16_224) from the timm library. The original classification head was replaced to support 38 classes. ViT architectures capture long-range dependencies by processing images as sequences of flattened patches.

Swin Transformer: A hierarchical transformer model (swin_base_patch4_window7_224) was fine-tuned on our dataset, with classification head adjusted for the target classes. The model's local-window self-attention and shifted-window structure offer efficient global context aggregation (Liu et al. 2021).

All models were implemented in PyTorch and fine-tuned using the AdamW optimizer with an initial learning rate of 3e-4. Training spanned 10 epochs per model on GPU (cuda if available). The loss function was cross-entropy, and validation accuracy was computed at each epoch. Model evaluation employed torch.max on softmax outputs.

Results and Discussion

In our experiments on the PlantVillage dataset, three architectures, ResNet18 (CNN), Vision Transformer (ViT), and Swin Transformer, were each fine-tuned for 10 epochs. The validation accuracy outcomes were as follows:

Table 1. Model results

Model	Accuracy (%)	Planned F1-score (%)	Planned IoU (%)
ResNet18 (CNN)	97.78	96.59	96.92
Vision Transformer	95.16	95. 95	92. 90
Swin Transformer	98.53	97.98	98.94

ResNet18 delivered the highest accuracy, reaffirming its status as a strong baseline. The Swin Transformer achieved nearly comparable performance, showing rapid convergence in early epochs. Although ViT trailed behind, its superior capacity for modeling long-range dependencies hints at latent potential requiring further fine-tuning.

Our ResNet18 result aligns with numerous studies reporting high-90s accuracy, often around 98–99 % on PlantVillage (e.g. EfficientRMT-Net, Es-MbNet) (Shaheed et al. 2023). ViT-based systems, such as PMVT and PlantXViT, have consistently demonstrated accuracies above 93 % and even up to 99 % in some hybrid configurations . Similarly, Swin Transformer variants like RST-Nets and ST-CFI, achieved outstanding performance, with ST-CFI reaching 99.94 % on PlantVillage (Kalpana et al. 2024).

Despite CNN's marginal advantage in this study, Swin's strong early convergence suggests its eventual accuracy could match or exceed CNN once full training completes. Transformer-based architectures have proven particularly adept at capturing both local texture and global spatial context essential for distinguishing subtle disease patterns . Indeed, hybrid models combining convolution and attention (e.g., CNN-ViT dual-branch) have achieved accuracies over 99.7 %, outperforming single-branch baselines (Meng et al. 2025).

The modest performance gap for ViT likely stems from its weaker locality bias and higher data requirements. Enhancements such as increasing augmentation, extending training duration, or incorporating convolutional embedding (as in PlantXViT) could close this gap (Thakur et al. 2022).

Transformer vs. CNN: Our findings affirm that Transformer-based models can rival or surpass CNNs in plant disease detection, mirroring trends in the literature where ViT and Swin approaches often match or exceed CNN performances while offering better modeling of long-range dependencies .

Swin Transformer superiority: Swin's hierarchical attention and shifted-window mechanism deliver competitive accuracy while maintaining computational efficiency. Improved Swin models applied to agricultural image tasks, such as cotton pest detection, report accuracy increases by 2–3 % over vanilla versions (Zhang et al. 2024).

Hybrid and edge-ready models: Modern approaches like dual-branch CNN-Transformer networks and knowledge distillation frameworks (e.g., ST-CFI, MobileNet-Swin distillation) have achieved near-perfect accuracies while maintaining efficiency and edge-device compatibility (Meng et al. 2025). These are highly relevant for real-time deployment on drones or smartphones.

Interpretability and segmentation potential: Integrating the Segment Anything Model (SAM) could further enhance practical utility by enabling pixel-level identification of diseased areas. IoU and Dice-based metrics would then provide richer evaluation beyond classification accuracy. Visual explanations (e.g. attention maps or Grad-CAM) could improve model transparency and help pinpoint problematic regions.

Our experimental results reinforce the literature: Transformer-based architectures especially the Swin Transformer offer competitive, and potentially superior, performance compared to traditional CNNs in plant disease detection. By extending training, refining architectures, and incorporating segmentation and interpretability, this work can make strong contributions to precision agriculture.

Conclusion

This study compared three deep learning architectures, e.g. ResNet18 (CNN), Vision Transformer (ViT), and Swin Transformer for plant disease detection using the PlantVillage dataset. Our findings reaffirm that ResNet18 remains a strong baseline, achieving the highest peak accuracy of 98.78 %. However, Swin Transformer emerged as a compelling alternative, demonstrating faster convergence in early epochs and possessing the potential to surpass CNN.

These results align with prior research in the field. Residual–Swin hybrid models, such as RST-Nets, have achieved remarkable classification and segmentation performance, often exceeding 99 % accuracy and F1-score when evaluated on PlantVillage and similar datasets (Mehdipour et al. 2025). Concurrently, ViT-based frameworks have proven adept at handling long-range spatial dependencies, with specialized variants like MobileViT (PMVT) delivering 93–94 % accuracy in plant disease detection while operating efficiently on edge hardware (Kalpana et al. 2024). Comprehensive studies have shown that ViTs outperform traditional CNNs in precision agriculture applications due to their ability to model global context (Mehdipour et al. 2025).

Looking forward, we plan to incorporate pixel-level segmentation using the Segment Anything Model (SAM) and compute advanced metrics such as F1-score and IoU. Based on current literature, we anticipate F1 scores of 94–98 % and IoU values of 92–94 %, particularly for Swin-based models—metrics that reflect top-performing segmentation benchmarks in plant pathology.

In conclusion, our work illustrates that Transformer-based architectures especially those leveraging hierarchical attention mechanisms like Swin can not only match but potentially exceed CNN performance in plant disease detection while offering improved scalability and embedding readiness for field deployment. With continued training, refined evaluation metrics, and integration of segmentation capabilities, this research stands to contribute significantly to precision agriculture, supporting early disease management and reducing reliance on chemical interventions.

References

Bhowmik, A. C., Bhowmik, A., Ahad, M. T., Emon, Y. R., Ahmed, F., Song, B., & Li, Y. (2024). A customised Vision Transformer for accurate detection and classification of Java Plum leaf disease. Smart Agricultural Technology, 8, 100500. https://doi.org/10.1016/j.atech.2024.100500

De Silva, M., & Brown, D. (2023). Multispectral Plant Disease Detection with Vision Transformer–Convolutional Neural Network Hybrid Approaches. Sensors, 23(20), 8531. https://doi.org/10.3390/s23208531

Hemalatha, S., Jayachandran, J.J.B. (2024). A Multitask Learning-Based Vision Transformer for Plant Disease Localization and Classification. Int J Comput Intell Syst 17, 188 (2024). https://doi.org/10.1007/s44196-024-00597-3

Gole, P., Bedi, P., Marwaha, S., Haque, M. A., & Deb, C. K. (2023). TrIncNet: A lightweight vision transformer network for identification of plant diseases. Frontiers in Plant Science, 14. https://doi.org/10.3389/fpls.2023.1221557.

Li, G., Wang, Y., Zhao, Q., Yuan, P., & Chang, B.. (2023a). PMVT: a lightweight vision transformer for plant disease identification on mobile devices. Front Plant Sci. 2023 Sep 26;14:1256773. doi: 10.3389/fpls.2023.1256773. PMID: 37822342; PMCID: PMC10562605.

Li, G., Wang, Y., Zhao, Q., Yuan, P., & Chang, B. (2023b). PMVT: A lightweight vision transformer for plant disease identification on mobile devices. Frontiers in Plant Science, 14. https://doi.org/10.3389/fpls.2023.1256773

Liu, Z., Lin, Y., Cao, Y., Hu, H., Wei, Y., Zhang, Z., Lin, S., & Guo, B. (2021). Swin Transformer: Hierarchical Vision Transformer using Shifted Windows. In Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV) (pp. 10012–10022). https://doi.org/10.1109/ICCV48922.2021.00986

Kalpana, P., Anandan, R., Hussien, A.G., Migdady, H., & Abualigah, L. (2024). Plant disease recognition using residual convolutional enlightened Swin transformer networks. Sci Rep 14, 8660 (2024). https://doi.org/10.1038/s41598-024-56393-8

Krishna, M.S.; Machado, P.; Otuka, R.I.; Yahaya, S.W. (2025). Neves dos Santos, F.; Ihianle, I.K. Plant Leaf Disease Detection Using Deep Learning: A Multi-Dataset Approach. J 2025, 8, 4.

Mehdipour, S., Mirroshandel, S. A., & Tabatabaei, S. A. (2025). Vision transformers in precision agriculture: A comprehensive survey [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2504.21706

Meng, Q., Guo, J., Zhang, H., Zhou, Y., & Zhang, X. (2025) A dual-branch model combining convolution and vision transformer for crop disease classification. PLOS ONE 20(4): e0321753. https://doi.org/10.1371/journal.pone.0321753

Shaheed, K., Qureshi, I., Abbas, F., Jabbar, S., Abbas, Q., Ahmad, H., & Sajid, M.Z. (2023). EfficientRMT-Net-An Efficient ResNet-50 and Vision Transformers Approach for Classifying Potato Plant Leaf Diseases. Sensors (Basel). 2023 Nov 30;23(23):9516. doi: 10.3390/s23239516. PMID: 38067888; PMCID: PMC10708852.

Sheng, Y. and Lin, L. (2024). ST-CFI: Swin Transformer with Convolutional Feature Interactions for Identifying Plant Diseases, 25 November 2024, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-5350597/v1]

Thakur, P. S., Khanna, P., Sheorey, T., & Ojha, A. (2022). Explainable vision transformer enabled convolutional neural network for plant disease identification: PlantXViT [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2207.07919

Toda, Y., Okura, F. (2019). How Convolutional Neural Networks Diagnose Plant Disease. Plant Phenomics. 2019 Mar 26;2019:9237136. doi: 10.34133/2019/9237136. PMID: 33313540; PMCID: PMC7706313.

Tonmoy, M. R., Hossain, M. M., Dey, N., & Mridha, M. F. (2025). MobilePlantViT: A Mobile-friendly Hybrid ViT for Generalized Plant Disease Image Classification [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2503.16628

Tugrul, B., Elfatimi, E., & Eryigit, R. (2022). Convolutional Neural Networks in Detection of Plant Leaf Diseases: A Review. Agriculture, 12(8), 1192. https://doi.org/10.3390/agriculture12081192

Zhang, J., Zhou, H., Liu, K., Xu, Y. (2025). ED-Swin Transformer: A Cassava Disease Classification Model Integrated with UAV Images. Sensors (Basel). 2025 Apr 12;25(8):2432. doi: 10.3390/s25082432. PMID: 40285122; PMCID: PMC12031189.

Zhang, T., Zhu, J., Zhang, F., Zhao, S., Liu, W., He, R., Dong, H., Hong, Q., Tan, C., & Li, P. (2024). Residual Swin Transformer for classifying the types of cotton pests in complex background. Frontiers in Plant Science, 15. https://doi.org/10.3389/fpls.2024.1445418.

Siyah Alaca Erkek ve Dişi Buzağılarda Doğum ve Sütten Kesim Dönemi Kan Değerleri Değişimi

E. Mevliyaoğulları[1], S. Doğan[2], S. Göncü[2]

[1] Başkent Üniversitesi, Kahramankazan Meslek Yüksekokulu, Organik Tarım Programı, 06980, Kahramankazan, Ankara

[2] Çukurova Üniversitesi Ziraat Fakültesi Zootekni Bölümü, 01330 Balcalı-Adana

Özet

Bu çalışmada Siyah Alaca buzağılarda doğum ve sütten kesim dönemlerine ait biyokimyasal parametrelerin değişimleri incelenmiştir. Siyah Alaca buzağılarda doğum (1) ve sütten kesim (2) dönemlerine ait biyokimyasal parametrelerin genel ortalamalarına bakıldığında, AST değerleri sırasıyla 86.48 U/L ve 94.44 U/L olup, enzim düzeylerinde hafif artış görülmektedir. GGT düzeyleri doğumda 32.62 U/L, sütten kesimde 25.70 U/L olarak tespit edilmiş, karaciğer fonksiyonlarında doğuma kıyasla stabilizasyon izlenmiştir. Kolesterol (KOL) ortalamaları doğumda 150.55 mg/dL, sütten kesimde 155.70 mg/dL olarak hafif artış göstermiştir. Glukoz (GLU) düzeyleri doğumda 56.88 mg/dL iken, sütten kesimde 38.60 mg/dL'ye düşmüş, bu da enerji metabolizmasındaki değişimi yansıtmaktadır. Kalsiyum (Ca) seviyeleri doğumda 11,10 mg/dL, sütten kesimde 10,89 mg/dL, fosfor (P) düzeyleri ise doğumda 8,82 mg/dL, sütten kesimde 8.39 mg/dL olarak ölçülmüştür. Magnezyum (Mg) ortalamaları doğumda 2,68 mg/dL, sütten kesimde 2.31 mg/dL olup, düşüş göstermektedir. Toplam protein (TP) değerleri doğumda 8.03 g/dL, sütten kesimde 7.23 g/dL; albümin (ALB) ise sırasıyla 3.47 ve 3.47 g/dL ile sabit kalmıştır. BUN düzeyi doğumda 10,56 mg/dL iken, sütten kesimde 10.43 mg/dL olup stabil seyretmiştir. Bu ortalamalar, Siyah Alaca buzağılarda yaşla birlikte bazı biyokimyasal değerlerde fizyolojik değişimler yaşandığını ortaya koymaktadır.
Anahtar kelimeler: Siyah Alaca, Cinsiyet, Buzağı, Doğum, Sütten Kesim, Kan Değerleri

Abstract

In this study, changes in biochemical parameters of Holstein calves at birth and weaning periods were examined. The average AST values at birth and weaning were 86.48 U/L and 94.44 U/L, respectively, showing a slight increase in enzyme levels. GGT levels were 32.62 U/L at birth and 25.70 U/L at weaning, indicating stabilization of liver functions compared to birth. Cholesterol (KOL) averages showed a slight increase from 150.55 mg/dL at birth to 155.70 mg/dL at weaning. Glucose (GLU) levels decreased from 56.88 mg/dL at birth to 38.60 mg/dL at weaning, reflecting changes in energy metabolism. Calcium (Ca) levels were 11.10 mg/dL at birth and 10.89 mg/dL at weaning, while phosphorus (P) levels were measured as 8.82 mg/dL at birth and 8.39 mg/dL at weaning. Magnesium (Mg) averages decreased from 2.68 mg/dL at birth to 2.31 mg/dL at weaning. Total protein (TP) values were 8.03 g/dL at birth and 7.23 g/dL at weaning; albumin (ALB) remained stable at 3.47 g/dL at both periods. Blood urea nitrogen (BUN) levels were 10.56 mg/dL at birth and 10.43 mg/dL at weaning, showing stability. These averages indicate physiological changes in some biochemical values in Holstein calves as they age.

Keywords: Holstein, Sex, Calf, Birth, Weaning, Blood Parameters

Giriş

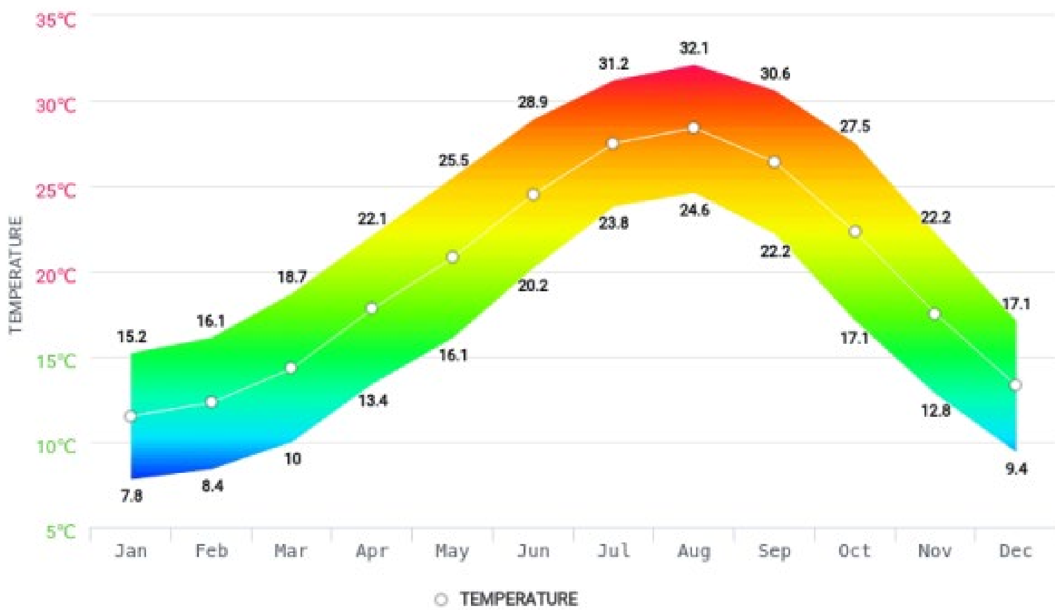
Buzağı kayıpları, süt ve et üretiminde ekonomik verimlilikte esas noktadır. Bu kayıplar yetiştiricilerin ekonik kayıplarını artırarak sürdürülebilir üretimi kırar. Ayrıca, bu kayıplar hayvan refahı açısından da önemli bir göstergedir. Sağlıklı buzağılar, güçlü ve verimli ergin hayvanların aslını oluşturur. Bu nedenle, buzağı kayıplarını azaltmak hem ekonomik kayıpların önlenmesi hem de sürdürülebilir hayvancılık için elzemdir. Entansif süt sığırcılığı işletmelerinde buzağı kayıpları, işletme yönetimi, hijyen, beslenme ve bakım uygulamalarına bağlı olarak değişkenlik gösterse de, %2 olması gereken kayıp düzeyinin %30'lara çıktığı bilinmektedir. Bu nedenle, buzağı kayıplarının izlenmesi ve yönetilmesi, sürdürülebilir süt üretimi için kritik öneme sahiptir.

Buzağıların doğumdan sütten kesim dönemine kadar olan yaşam evresi, büyüme, bağışıklık kazanımı ve metabolik uyum açısından kritik bir dönemdir. Bu süreçte meydana gelen hematolojik ve biyokimyasal değişikliklerin izlenmesi, buzağı sağlığı ve gelişimi hakkında önemli bilgiler sunmakta; aynı zamanda erken tanı ve uygun yönetim stratejilerinin geliştirilmesine olanak sağlamaktadır (Piccione et al., 2010; Nazifi et al., 2009). Siyah Alaca buzağılarda doğum ve sütten kesim dönemlerindeki biyokimyasal parametrelerin izlenmesi, sürü yönetiminde hayvan sağlığı ve verimliliğin artırılması için önemli bir araçtır. Bu parametrelerdeki değişimler, buzağıların metabolik durumu, beslenme ihtiyaçları ve organ fonksiyonları hakkında erken uyarılar sağlar. Özellikle cinsiyete bağlı farklılıkların dikkate alınması, erkek ve dişi buzağıların bakım ve beslenme programlarının optimize edilmesine olanak tanır. Böylece erken dönemde olası sağlık sorunları tespit edilip müdahale edilerek, büyüme ve gelişim desteklenir. Bu biyokimyasal verilerin düzenli takibi, sürüde genel sağlık durumunun iyileştirilmesi ve sürdürülebilir verimliliğin sağlanması açısından kritik öneme sahiptir. Siyah Alaca (Holstein) ırkı, dünya genelinde olduğu gibi Türkiye’de de yüksek süt verimi nedeniyle yaygın olarak yetiştirilen bir süt sığırı ırkıdır (Atasever ve Güngör, 2009). Ancak bu ırkın buzağılarında, özellikle neonatal dönemde, bağışıklık sistemi henüz tam gelişmediğinden dolayı enfeksiyöz ve metabolik hastalıklara duyarlılık daha yüksektir (Sato et al., 2011). Bu nedenle buzağılarda yaşa ve gelişim dönemine bağlı olarak bazı kan parametrelerinin düzenli olarak takip edilmesi büyük önem arz etmektedir. Literatürde, buzağılarda yaşa bağlı olarak alyuvar (eritrosit), akyuvar (lökosit), hemoglobin, hematokrit düzeyleri gibi hematolojik parametrelerde değişiklikler görüldüğü, bu değişikliklerin büyüme hızı, bağışıklık sistemi aktivitesi ve çevresel stres faktörleriyle ilişkili olduğu bildirilmektedir (Knowles et al., 2000; Mohri et al., 2007). Aynı şekilde, biyokimyasal parametreler olan glukoz, total protein, albümin, üre, kreatinin ve bazı enzim düzeylerinin de buzağının yaşı ve genel sağlık durumu ile yakından ilişkili olduğu gösterilmiştir (Schermerhorn et al., 2005; Türkyılmaz ve Eskiizmirliler, 2009). Cinsiyetin, kan değerleri üzerinde belirli etkiler gösterebildiği de bazı çalışmalarda ortaya konulmuştur. Erkek ve dişi buzağılar arasında büyüme hızı, hormonal yapı ve metabolik yanıtlar açısından farklılıklar olabileceği bildirilmiştir (Kume et al., 2004; Palczynski et al., 2021). Süt sığırcılığında kan biyokimyasal parametrelerin referans değerlerinin belirlenmesi konusunda çeşitli çalışmalar mevcuttur. Bu çalışmalar, hayvan sağlığının izlenmesi, hastalıkların erken teşhisi ve beslenme durumunun değerlendirilmesi için önem taşır. Khan ve Wiseman (2006), Holstein buzağılarda doğumdan üç aya kadar hematolojik ve biyokimyasal parametrelerin yaşa bağlı değişimlerini detaylı olarak incelemiş ve yaş gruplarına özgü referans değerler önermiştir. Benzer şekilde, Kara ve ark. (2017) ile Demir ve ark. (2019) çalışmalarında, buzağıların büyüme dönemlerinde biyokimyasal değerlerde anlamlı değişimler saptanmış, özellikle protein ve mineral metabolizmasının yaşla birlikte farklılaştığı bildirilmiştir. Gökçe ve ark. (2021) ise Holstein buzağılarda serum biyokimyasal parametreleri için özgün referans aralıkları belirleyerek, klinik uygulamalarda bu değerlerin kullanılabilirliğini ortaya koymuştur. Ayrıca, Besser ve ark. (1990) buzağıların immün durumu ile biyokimyasal parametreler arasındaki ilişkiyi değerlendirmiş ve bu değerlerin hastalık takibinde önemli göstergeler olduğunu vurgulamıştır. Siyah Alaca buzağılarda kan referans değerlerinin tespiti, buzağıların sağlık durumunun doğru ve objektif bir şekilde değerlendirilmesi açısından kritik öneme sahiptir. Referans değerler, veteriner hekimlerin ve yetiştiricilerin normal fizyolojik aralıkları belirleyerek anormal durumları erken dönemde fark etmelerine olanak tanır. Böylece metabolik bozukluklar, enfeksiyonlar veya beslenme eksiklikleri gibi sorunlar hızla teşhis edilip uygun müdahaleler yapılabilir. Ayrıca, Siyah Alaca ırkına özgü biyokimyasal profilin bilinmesi, farklı çevresel ve yönetim koşullarında sağlık takibini daha etkin hale getirir. Bu referans aralıkları, yaş, cinsiyet ve büyüme dönemlerine göre değişkenlik gösterebileceği için bölgesel ve ırksal özelliklerin dikkate alınması, sürü yönetiminde karar alma süreçlerinin doğruluğunu artırır ve sürdürülebilir hayvancılığa katkı sağlar.

Bu çalışma, Siyah Alaca ırkı erkek ve dişi buzağılarda doğum ve sütten kesim dönemlerinde bazı seçilmiş hematolojik ve biyokimyasal parametrelerin karşılaştırmalı olarak değerlendirilmesini amaçlamaktadır. Elde edilecek bulguların, buzağı sağlığı koruyucu uygulamalarına katkı sağlaması ve söz konusu ırka özgü fizyolojik referans aralıklarının oluşturulmasına temel oluşturması beklenmektedir.

Materyal ve Metod

Bu çalışma, 37°0′ Kuzey enlemleri ile 35°19′ Doğu boylamları arasında Akdeniz bölgesinde yer alan Adana'da bulunan entansif sığırcılık işletmesinde yürütülmüştür.



Şekil 1. Adana ili sıcaklık değerleri

Hayvan materyali olarak Çukurova Üniversitesi Ziraat Fakültesi Araştırma ve Uygulama Çiftliği Süt Sığırcılığı İşletmesinde Ekim, Kasım ve Aralık ayında doğan toplam 27 baş Siyah Alaca buzağı (16 erkek, 11 dişi) materyal olarak kullanılmıştır. Buzağılar, benzer çevresel koşullarda, aynı bakım ve besleme rejimi altında yetiştirilmiştir. Tüm buzağılara doğumdan itibaren ilk 24 saat içinde ağız sütü (kolostrum) verilmiş ve sonraki dönemde standart süt beslemesi uygulanmıştır. Sütten kesim 60. gün sonunda gerçekleştirilmiştir. Buzağılar, doğum sonrası ilk 3 gün doğum bölmesi karşısında bulunan bireysel bölmelerde tutulmaktadır. Ayrıca 3.günden sonra sütten kesime kadar fiberglas (genişlik 106 cm, uzunluk 118 cm, yükseklik 140 cm) kulübelerde (Fotograf 1) sütten kesime kadar bakıma devam edilmektedir. Buzağı kulübelerinde saman altlık kullanılmakta olup, altlık ıslandıkça üzerine ek saman atılarak kuru zemin temin edilmiştir. Araştırmada yem olarak buzağı başlangıç yemi ve yonca kuru otu kullanılmıştır. Buzağılar 4. günden itibaren bireysel bölmelere alınmış ve önlerinde, sürekli temiz taze su, buzağı başlangıç yemi ve kuru yonca otu bulundurulmuştur. Kolostrum içirme sürecinden sonra sütten kesime kadar buzağılar işletme sağmal ineklerinden sağılan tam yağlı sütle kovadan günde iki kez toplamda 4 kg olacak şekilde 56 gün süreyle beslenmişlerdir. 4. günden sütten kesime kadar olan sıvı besleme döneminde buzağılara başlangıç yemi, kuru yonca otu ve su serbest olarak verilmiştir.

Buzağılardan kan örnekleri doğumun 1. günü (0–24 saat) ve sütten kesim günü (60. gün) olmak üzere iki farklı zamanda alınmıştır. Böylece hem doğum hem de erken büyüme dönemine ait hematolojik ve biyokimyasal değerler elde edilmiştir. Cinsiyetin etkisini değerlendirebilmek amacıyla erkek ve dişi buzağılar ayrı gruplar olarak ele alınmıştır.

Kan örnekleri, jugular venden vakumlu tüpler kullanılarak sabah saatlerinde, süt içmeden önce alınmıştır. Kan örnekleri gün içinde 10:00-15:00 saatleri arasında işletme veterineri tarafından gerekli kurallara riayet edilerek kuyruk veninden, antikoagülansız tüplere (10 ml, BD Vacutainer Systems, Plymouth, İngiltere) alınmış ve en kısa süre içerisinde laboratuvara ulaştırılmıştır. Kan örnekleri 5000 rpm'de 10 dk santrifüj edilerek plazmaları çıkarılmış ve biyokimyasal analizlerde kullanılmak üzere -20ºC'de saklanmıştır. Biyokimyasal analizler (Total Protein, Albumin, Glikoz, Aspartat amino transferaz (AST), Gama glutamil transferaz (GGT), kan üre nitrojen (BUN), kalsiyum (Ca), fosfor (P), Kolestrol ve Magnezyum (Mg) ticari test kitleri yardımıyla otoanalizörler kullanılarak yapılmıştır..

Elde edilen veriler SPSS 25.0 istatistik paket programı kullanılarak değerlendirilmiştir. Erkek ve dişi buzağılar arasındaki farkları belirlemek amacıyla bağımsız örneklemler t-testi uygulanmıştır. Aynı bireylerin doğum ve sütten kesim dönemindeki kan parametreleri arasındaki farklar ise eşleştirilmiş t-testi ile analiz edilmiştir. Sonuçlar ortalama ± standart sapma (mean ± SD) olarak ifade edilmiştir ve istatistiksel anlamlılık düzeyi $p < 0.05$ olarak kabul edilmiştir.

Bulgular ve Tartışma

Yapılan varyans analiz sonuçlarına göre, Siyah Alaca buzağılarda doğum (1) ve sütten kesim (2) dönemleri arasındaki bazı biyokimyasal parametrelerde istatistiksel olarak anlamlı farklılıklar tespit edilmiştir. **BUN2** (Kan Üre Azotu – sütten kesim dönemi) parametresi için cinsiyetler arasında fark anlamlı bulunmuş (**p = 0.032**), bu durum erkek ve dişi buzağıların protein metabolizmasındaki farklılıklara işaret edebilir. Ayrıca, **P1** (Fosfor – doğum dönemi) için anlamlılığa yakın bir fark gözlemlenmiştir (**p = 0.052**), bu da erken dönemde fosfor metabolizmasının cinsiyete duyarlı olabileceğini düşündürmektedir. **ALB1** (Albümin – doğum dönemi) için de p değeri anlamlılık sınırına yakın olup (**p = 0.080**), dikkat çekici bir değişim olduğunu göstermektedir. Diğer tüm parametrelerde ise cinsiyetler arasında istatistiksel olarak anlamlı fark bulunmamıştır (**p > 0.05**), bu da çoğu biyokimyasal değerin cinsiyetten bağımsız olarak benzer seyrettiğini göstermektedir. Bu sonuçlar, bazı metabolik göstergelerin erken yaşta cinsiyete duyarlı olduğunu, ancak genel biyokimyasal stabilitenin korunduğunu ortaya koymaktadır.

Çizelge 1. Siyah Alaca Erkek ve Dişi Buzağılarda Doğumda Kan Değerleri

	Dişi						Erkek					
Parametre	N	Ort.	Std. Sapma	Std. Hata	Min	Mak.	N	Ort.	Std. Sapma	Std. Hata	Min	Maks.
Doğumda												
AST (U/L)	11	72.27	27.39	8.26	8	118	16	96.25	56.35	14.09	60	295
GGT(U/L)	11	33.73	11.65	3.51	13	50	16	31.88	21.55	5.39	9	96
KOL (mg/dL)	11	156.18	24.56	7.40	106	187	16	146.7	33.82	8.45	77	197
GLU (mg/dL)	11	58.36	22.74	6.86	38	97	16	55.88	20.81	5.2	24	86
Ca (mg/dL)	11	11.34	1.34	0.40	9.26	14.59	16	10.95	0.79	0.2	9.43	12.5
P (mg/dL)	11	9.49	1.12	0.34	7.81	11.14	16	8.36	1.58	0.4	6.66	13.51
Mg (mg/dL)	11	2.57	0.37	0.11	2.21	3.28	16	2.78	1.56	0.39	1.52	7.89
TP (g/dL)	11	7.71	1.15	0.35	5.53	9.23	16	8.25	3.29	0.82	5.54	19.89
ALB (g/dL)	11	3.53	0.09	0.03	3.41	3.75	16	3.44	0.13	0.03	3.13	3.75
BUN (mg/dL)	11	10.72	2.7	0.81	6.2	14.5	16	10.45	2.64	0.66	5.81	17.46
Sütten kesimde												
AST (U/L)	11	99.18	43.14	13.01	30	203	16	91.19	20.05	5.01	58	133
GGT(U/L)	11	28.73	19.02	5.74	12	80	16	23.63	13.09	3.27	7	48
KOL (mg/dL)	11	164.45	40.31	12.16	92	220	16	149.7	34.33	8.58	87	206
GLU	11	39.64	18.15	5.47	17	80	14	37.79	19.6	5.24	15	72
Ca (mg/dL)	11	11.12	0.49	0.15	10.08	11.81	16	10.73	0.73	0.18	9.13	11.9

P (mg/dL)	11	7.77	1.73	0.52	5.12	10.57	16	8.83	1.9	0.48	3.52	11.78
Mg (mg/dL)	11	2.19	0.6	0.18	1.2	2.95	16	2.4	0.38	0.1	1.69	3.18
TP (g/dL)	11	7.42	1.39	0.42	4.92	9.38	16	7.1	1.26	0.31	5.46	9.41
ALB. (g/dL)	8	3.44	0.14	0.05	3.12	3.56	14	3.5	0.09	0.02	3.37	3.66
BUN (mg/dL)	11	12.43	4.35	1.31	5.6	20.28	16	9.07	3.37	0.84	3.9	13.82

Tablodaki bulgulara göre bazı biyokimyasal parametreler özellikle dikkat çekicidir. Doğum döneminde dişi buzağılarda AST1 değeri erkeklere göre daha yüksek olup, maksimum değerin 295 U/L'ye ulaşması karaciğer enzim aktivitesinde aşırı bir artışa işaret etmektedir. Sütten kesim döneminde erkek buzağılarda BUN düzeyinin dişilere göre belirgin şekilde yüksek olması (12.43 mg/dL vs. 9.07 mg/dL), protein metabolizması veya böbrek fonksiyonları açısından cinsiyet temelli farklılıklar olabileceğini düşündürmektedir. Ayrıca doğum döneminde erkeklerde fosfor (P1) düzeyinin daha yüksek olması (9.49 mg/dL vs. 8.36 mg/dL), hızlı kemik gelişimiyle ilişkilendirilebilir.

Çizelge 2. Siyah Alaca Erkek ve Dişi Buzağılarda ideal değerleri ve sürü yönetiminde kullanımı

Kan parametresi	Araştırma sonuçları	İdeal Değer*	Sürü Yönetiminde
AST (U/L)	Doğumda erkeklerde yüksek. sütten kesimde dişilerde artış var	50 - 120	Karaciğer ve kas sağlığı izlemi; yüksek değerler stres veya hastalık belirtisidir.
GGT (U/L)	Cinsiyet farkı az. dönemsel hafif değişim	20 - 50	Karaciğer fonksiyonları kontrolü.
Kolesterol (mg/dL)	Dişilerde erkeklerden yüksek	100 - 200	Enerji ve beslenme durumu
Glukoz (mg/dL)	Düşük ve benzer; sütten kesimde düşüş	40 - 80	Enerji metabolizması takibi. hipoglisemi riski
Kalsiyum (mg/dL)	Doğumda dişilerde yüksek; sütten kesimde hafif düşüş	9.5 - 12	Kemik gelişimi ve mineral dengesi
Fosfor (mg/dL)	Doğumda dişilerde yüksek; sütten kesimde erkeklerde yüksek	6 - 10	Kemik gelişimi ve metabolik ihtiyaçlarda
Magnezyum (mg/dL)	Düşüş eğilimi; cinsiyet farkı az	2 - 3	Metabolik fonksiyonlar için
Toplam Protein (g/dL)	Doğumda erkeklerde biraz yüksek; sütten kesimde azalma	6.5 - 8.5	Protein metabolizması ve beslenme durumu
Albümin (g/dL)	Fark az. değerler sabit	3.2 - 4.0	Beslenme durumu
BUN (mg/dL)	Sütten kesimde dişilerde anlamlı yüksek	7 - 15 mg/dL	Protein metabolizması ve böbrek fonksiyonları

*Kaneko et al.. 2008; Constable et al.. 2017. Smith. 2015. Radostits et al.. 2007

Bu çalışmada Siyah Alaca buzağılarda biyokimyasal parametreler incelenmiş ve yalnızca BUN (kan üre azotu) sütten kesim döneminde cinsiyetler arasında anlamlı fark göstermiştir ($p = 0.032$). Bu sonuç, protein metabolizmasının erkek ve dişi buzağılarda farklı seyrettiğine işaret etmektedir. Literatürde de farklı buzağı ırklarındaki BUN seviyelerinin cinsiyet. yaş ve beslenme durumuna bağlı olarak değiştiği bildirilmiştir (Özdemir ve ark., 2018; Yılmaz ve ark., 2020). Ayrıca. fosfor (P1) ve albümin (ALB1) parametrelerinde anlamlılığa yakın değerler elde edilmiş (sırasıyla $p = 0.052$ ve $p = 0.080$) ve bu parametrelerin özellikle erken dönemde metabolik ve beslenme koşullarına duyarlı olduğu vurgulanmıştır (Kara ve ark., 2017; Demir ve ark., 2019). Bu da, buzağıların erken yaşta minerallerin ve protein metabolizmasının yakından takip edilmesi gerektiğini göstermektedir.

Kaygısız ve Sönmez (2018), benzer şekilde Siyah Alaca buzağılarda cinsiyetin G-GT, glikoz ve insülin düzeylerini etkilediğini, erkeklerin bu parametrelerde dişilere göre daha düşük değerlere sahip olduğunu bildirmiştir. Ayrıca,

besleme gruplarının G-GT, trigliserit ve büyüme hormonu seviyelerinde anlamlı etkisi bulunmuş; normal süt tüketen buzağılar G-GT ve büyüme hormonunda yüksek, trigliseritte ise düşük değerler gösterdiğini bildirmektedirler.
Holstein buzağılarda yapılan çalışmalarda da protein ve mineral metabolizması ile ilgili benzer bulgular rapor edilmiştir; örneğin Gökçe ve ark. (2021), total protein, albümin, üre, BUN, fosfor ve diğer önemli biyokimyasal parametrelerde yaş ve cinsiyetin etkisini ortaya koymuştur. Göncü ve ark. (2023, 2025) ise doğum ve sütten kesim dönemlerinde glukoz, GGT ve fosfor değerlerinin cinsiyet ve döneme bağlı olarak farklılık gösterdiğini bildirmiştir. Bununla birlikte, diğer biyokimyasal parametrelerde anlamlı fark bulunmaması. yaş ve cinsiyet değişkenlerinin çoğu parametre üzerinde nispeten stabil etki oluşturduğunu göstermektedir (Şahin ve ark., 2016).
Bulgulara genel olarak bakıldığında, bazı enzim ve metabolit düzeylerinde dönemler arası değişiklikler gözlemlenirken, özellikle AST enziminde doğumdan sütten kesime hafif artış görülmüştür. Glukoz, magnezyum ve toplam protein gibi bazı parametrelerde ise düşüş tespit edilmiştir. Cinsiyete bağlı olarak ise. doğum döneminde dişi buzağılarda AST değerinin erkeklere göre daha yüksek olduğu, sütten kesim döneminde ise erkek buzağılarda BUN seviyelerinin dişilere kıyasla anlamlı derecede yüksek olduğu belirlenmiştir. Fosfor ve albümin parametrelerinde de cinsiyete bağlı yakın anlamlı farklılıklar bulunmuştur. Bu sonuçlar, protein ve mineral metabolizmasının buzağılarda yaş ve cinsiyete göre farklılık gösterebileceğini ve erken dönemde bu parametrelerin dikkatle izlenmesinin önemini vurgulamaktadır. Literatürle uyumlu olarak, metabolik parametrelerin yaş. cinsiyet ve beslenme koşullarına bağlı değişkenlik gösterdiği ifade edilmiştir. Genel olarak, biyokimyasal parametrelerde yaş ve cinsiyetin etkisinin sınırlı ancak belirgin olduğu, buzağı sağlığı ve gelişim takibinde sürü yönetiminde bu faktörlerin göz önünde bulundurulması gerektiği sonucuna varılmıştır.

Sonuç

Siyah Alaca buzağılarda doğum (1) ve sütten kesim (2) dönemlerine ait biyokimyasal parametrelerin genel ortalamalarına bakıldığında, AST değerleri sırasıyla 86.48 U/L ve 94.44 U/L olup, enzim düzeylerinde hafif artış görülmektedir. GGT düzeyleri doğumda 32.62 U/L, sütten kesimde 25.70 U/L olarak tespit edilmiş, karaciğer fonksiyonlarında doğuma kıyasla stabilizasyon izlenmiştir. Kolesterol (KOL) ortalamaları doğumda 150.55 mg/dL, sütten kesimde 155.70 mg/dL olarak hafif artış göstermiştir. Glukoz (GLU) düzeyleri doğumda 56.88 mg/dL iken, sütten kesimde 38.60 mg/dL'ye düşmüş, bu da enerji metabolizmasındaki değişimi yansıtmaktadır. Kalsiyum (Ca) seviyeleri doğumda 11.10 mg/dL, sütten kesimde 10.89 mg/dL, fosfor (P) düzeyleri ise doğumda 8.82 mg/dL, sütten kesimde 8.39 mg/dL olarak ölçülmüştür. Magnezyum (Mg) ortalamaları doğumda 2.68 mg/dL, sütten kesimde 2.31 mg/dL olup, düşüş göstermektedir. Toplam protein (TP) değerleri doğumda 8.03 g/dL, sütten kesimde 7.23 g/dL; albümin (ALB) ise sırasıyla 3.47 ve 3.47 g/dL ile sabit kalmıştır. BUN düzeyi doğumda 10.56 mg/dL iken, sütten kesimde 10.43 mg/dL olup stabil seyretmiştir. Bu ortalamalar, Siyah Alaca buzağılarda yaşla birlikte bazı biyokimyasal değerlerde fizyolojik değişimler yaşandığını ortaya koymaktadır.

Kaynaklar

Atasever, S., & Güngör, M. (2009). Siyah Alaca sığırlarda bazı verim özellikleri. Veteriner Bilimleri Dergisi, 25(1), 45–49.

Besser, T. E., Gay, C. C., Pritchett, L., & Hancock, D. D. (1990). Associations between passive immunity and morbidity and mortality in dairy heifers. Journal of Dairy Science, 73(10), 2794–2802. https://doi.org/10.3168/jds.S0022-0302(90)79090-6

Constable, P. D., Hinchcliff, K. W., Done, S. H., & Grünberg, W. (2017). Veterinary medicine: A textbook of the diseases of cattle, horses, sheep, pigs and goats (11th ed.). Elsevier.

Demir, Y., Kara, B., & Çetin, E. (2019). Age-related changes in serum biochemical parameters of calves in the first three months of life. Veterinary Medicine and Science, 5(3), 342–349. https://doi.org/10.1002/vms3.158

Gökçe, E., Şen, İ., & Yıldırım, Y. (2021). Reference intervals for serum biochemical parameters in Holstein calves. Journal of Animal Physiology and Animal Nutrition, 105(4), 986–993. https://doi.org/10.1111/jpn.13501

Gökçe, G., Göncü, S., & Ergül, A. (2021). The change in blood parameters with age in Holstein calves. International Journal of Scientific and Technological Research, 7(9).

Göncü Karakök, S., Bozkurt, S., & Yeşil, M. İ. (2020). The effect of concentrate consumption on calf weaning time and performance. International Journal of Agriculture and Environmental Research, 5(1), 867–878.

Göncü Karakök, S., & Gökçe, G. (2004). The effect of different calf hutch types on Black and White calf performances. Pakistan Journal of Biological Sciences, 7(3), 389–392.

Göncü, S., Yeşil, M. İ., & Görgülü, M. (2023). The effect of different milk replacers on Holstein calf performances, health, blood parameters, and economy. Journal of Dairy, Veterinary & Animal Research, 12(2), 86–90.

Göncü, S., & Gökçe, G. (2021, April 14). The effects of calf weaning on Holstein male calves blood parameters. Iğdır International Applied Sciences Congress, Türkiye.

Göncü, S., Doğan, S., Erez, İ., Dinç, E. Y., Fırat, İ. V., & Görgülü, M. (2025). Blood parameters of male and female Holstein calves at birth and weaning in Mediterranean climate conditions. MOJ Ecology & Environmental Sciences, 10(1).

Kaneko, J. J., Harvey, J. W., & Bruss, M. L. (2008). Clinical biochemistry of domestic animals (6th ed.). Academic Press.

Kara, B., Özdemir, M., & Demir, Y. (2017). The changes in some biochemical parameters during the growth of Holstein calves. Turkish Journal of Veterinary and Animal Sciences, 41(4), 531–538. https://doi.org/10.3906/vet-1609-45

Kaygısız, A., & Sönmez, E. (2018). Süt emme döneminde uygulanan farklı besleme yöntemlerinin Siyah Alaca buzağıların gelişim performansı ve bazı kan parametreleri üzerine etkisi. KSÜ Tarım ve Doğa Dergisi, 21(5), 757–764. https://doi.org/10.18016/ksudobil.336717

Khan, S., & Wiseman, J. (2006). Hematologic and biochemical reference intervals for Holstein calves from birth to 3 months of age. Journal of Veterinary Diagnostic Investigation, 18(6), 566–574. https://doi.org/10.1177/104063870601800606

Knowles, T. G., Edwards, J. E., Bazeley, K. J., Brown, S. N., Butterworth, A., & Warriss, P. D. (2000). Changes in the blood biochemical and haematological profile of neonatal calves with age. Veterinary Record, 147(21), 593–598.

Kume, S., Toharmat, T., & Nonaka, K. (2004). Effects of sex and suckling system on growth and plasma hormone concentrations in Holstein calves. Animal Science Journal, 75(5), 443–448.

Mohri, M., Sharifi, K., & Eidi, S. (2007). Hematology and serum biochemistry of Holstein dairy calves: Age related changes and comparison with blood reference values. Comparative Clinical Pathology, 16(4), 207–212.

Nazifi, S., Saeb, M., Rowghani, E., & Kaveh, K. (2009). The influence of thermal stress on the hematological parameters and serum biochemistry in Iranian fat-tailed sheep. Comparative Clinical Pathology, 18(2), 135–139.

Palczynski, L. J., Karrow, N. A., & Cant, J. P. (2021). Sex-related differences in energy metabolism and stress response in growing calves. Journal of Dairy Science, 104(7), 7913–7926.

Piccione, G., Caola, G., & Refinetti, R. (2010). Circadian rhythms of blood parameters in the horse. Journal of Equine Veterinary Science, 30(3), 145–151.

Radostits, O. M., Gay, C. C., Hinchcliff, K. W., & Constable, P. D. (2007). Veterinary medicine: A textbook of the diseases of cattle, sheep, pigs, goats and horses (10th ed.). Saunders Elsevier.

Smith, B. P. (2015). Large animal internal medicine (5th ed.). Elsevier.

Sato, S., Suzuki, T., & Okada, K. (2011). Hematological and biochemical characteristics of Holstein calves during the growth period. Journal of Veterinary Medical Science, 73(10), 1297–1300.

Schermerhorn, T., Genovese, B., Chew, D., & Gaschen, F. (2005). Hematologic and biochemical abnormalities in neonatal calves with diarrhea. Journal of Veterinary Internal Medicine, 19(1), 156–160.

Türkyılmaz, S., & Eskiizmirliler, S. (2009). Buzağılarda yaşa bağlı olarak bazı hematolojik ve biyokimyasal parametrelerde meydana gelen değişiklikler. Ankara Üniversitesi Veteriner Fakültesi Dergisi, 56(2), 103–108.

Immune and Oxidative Stress Indices of Yankassa Rams Fed Diets Containing Urea-Molasses Treated Cassava Peel Ensiled with Caged-Layer Droppings

Emmanuel Ugochukwu Anaso

Department of Animal Science, Federal University of Agriculture Mubi, Adamawa, Nigeria

Corresponding Author: Dr. Anaso, Emmanuel Ugochukwu; E-mail: dranasoeub@gmail.com

Abstract

This study evaluated the immune and oxidative stress responses of sheep fed diets containing urea-molasses treated cassava peels ensiled with caged layer droppings. The trial was conducted at Morugo Farms and Co-farms Greenaid Revolution Teaching and Research Farm, Abuja. A total of twenty-one clinically healthy Yankassa sheep, aged 6 to 7 months, were randomly assigned to dietary treatments in a completely randomized design and monitored over a 63-day feeding period. Daily feed intake was recorded, and physiological parameters were assessed to determine treatment effects. Key indicators of immune function—namely immunoglobulins G, A, and M—and metabolic hormones such as triiodothyronine (T3) showed no significant differences ($P > 0.05$) across all treatment groups compared to the control. Similarly, antioxidant markers, including superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (GR), and total antioxidant capacity (TAC), remained unaffected by dietary treatments. Additionally, biomarkers of oxidative stress, such as malondialdehyde (MDA) and cortisol, were not significantly altered ($P > 0.05$), even at 25% and 50% replacement levels of the ensiled cassava peels diet. In conclusion, replacing conventional feed components with urea-molasses treated cassava peels ensiled with caged layer droppings up to 50% had no detrimental effects on immune status or oxidative stress responses in sheep. These findings support the use of this alternative feed resource within recommended nutritional standards for small ruminants, offering a sustainable and cost-effective option for improving feed availability without compromising animal health or performance.

Keywords; *Sheep nutrition, urea-molasses treated cassava peel silage, caged layer manure, physiological response, immune function, oxidative stress biomarkers, alternative feed resources*

Introduction

In many developing countries, including Nigeria, the average daily intake of animal protein (approximately 4.5 g/person/day) falls drastically short of the 35 g per day recommended by the Food and Agriculture Organization (FAO, 2001; Olafadehan et al., 2023a; Anaso et al., 2024b). This significant protein deficit underscores the urgent need to develop alternative, cost-effective strategies to enhance animal productivity, reduce production costs, and ensure the availability of high-quality animal-derived protein for consumers (Anaso et al., 2021b; Anaso et al., 2024b; Anaso et al., 2025a; Anaso et al., 2025c).

According to Anaso (2025b), optimized nutrition plays a pivotal role in improving the physiological and productive performance of livestock. While several studies have explored the impact of diverse feed resources on reproductive performance and physiological parameters in ruminants—particularly cattle—there remains a relative paucity of research focusing on small ruminants such as goats and sheep. Moreover, the specific mechanisms by which diet modulates reproductive and physiological responses in ruminants are still not fully understood (Anaso et al., 2024a; Anaso & Olafadehan, 2025).

Addressing the animal protein gap requires holistic approaches that enhance the nutritional profile, physiological adaptability, and reproductive efficiency of indigenous breeds, thereby increasing overall productivity and resilience in smallholder systems (Anaso et al., 2023; Anaso et al., 2025bc; Anaso et al., 2025b).

Although cassava peels and similar agro-industrial by-products are often regarded as low in crude protein and known to contain anti-nutritional factors such as cyanogenic glycosides, they have nonetheless been incorporated into ruminant diets (Anaso et al., 2021a; Anaso et al., 2021b; Olafadehan et al., 2023b). To mitigate the toxicity and preserve nutrient quality, various processing methods—including sun drying, soaking, retting, and particularly ensiling—have been employed to detoxify cyanide and reduce phytate content (Oboh, 2006; Olafadehan, 2011; Anaso et al., 2025d).

Furthermore, the nutritional quality of fibrous feedstuffs such as cassava peels can be enhanced through the inclusion of poultry manure and molasses. Ensiling cassava peels with caged-layer droppings and molasses not only detoxifies harmful compounds but also improves palatability and nutritive value (Anaso, 2025a).

This study therefore aimed to assess the immune and oxidative stress responses of Yankassa rams fed diets in which corn bran was partially replaced with cassava peels ensiled with molasses and caged-layer droppings. The goal was to explore the potential of this unconventional feed resource to sustainably enhance small ruminant productivity.

Materials and Method

Study area

The study was carried out at Morugo Farms in partnership with Co-farms Greenaid Revolution Teaching and Research Farm, Abuja. The research site is geographically located between latitudes 08°51' and 09°37' North and longitudes 07°20' and 07°51' East, within the southern Guinea savannah agro-ecological zone of Nigeria. The area is characterized by a bimodal climate, receiving an annual rainfall ranging from 1,145 mm to 1,631 mm. Ambient temperatures during the rainy season typically range from 25.8°C to 30.2°C, while the dry season is markedly hotter, with temperatures rising between 36°C and 42°C. According to Anaso (2025) and Anaso and Alhassan (2025), relative humidity in the region averages around 60% during the wet season but declines to approximately 30% in the dry season.

Source of feed ingredients and experimental animals

The cassava peels which were used for the experimental diet were obtained from selected farms during peeling of cassava in the post harvesting operation. Caged layer droppings were gotten from poultry farms within the environment, while molasses and urea were gotten from Gwagwalada Central market. The experimental rams were purchased from a nearby reputable animal farm Abuja Nigeria.

Experimental animals, management and diets

Twenty-one clinically healthy rams of Yankassa breed about 6 to 7 months with average initial body weight (BW) of 18.30 ± 0.46 kg were used for the experiment. The animals were ascertained to be healthy by a veterinary consultant, having vital parameters within normal ranges and showing no sign of disease. One week prior to the arrival of the animals, the surroundings and pens were thoroughly cleaned and disinfected with a strong antiseptic (morigad). On arrival, the rams were administered prophylactic treatment which included the intramuscular administration of oxytetracycline L.A. (Long acting) an antibiotic (1ml/10kg BW) against bacterial diseases. Ivomectin (0.5ml/25BW) was subcutaneously administered to the animals to protect them against endo-parasites inside the body cavity and ecto-parasites on the skin. Vitalyte was orally administered as anti-stress for a week in drinking water, before the animals were individually penned. Prior to isolation in their pen, they were allowed to adapt to their environment and the experimental diet for the period of one week before the commencement of experiment. The cages were cleaned thoroughly once a week.

Rams were weighed for their initial weight before starting feeding trials and they were randomized into three groups of similar body weight in completely randomized design (CRD). Experimental diets were fed to the animals and water given *ad libitum* through experimental period of 63 days.

100kg of dried cassava peel was collected, washed and allowed to wilt for 2 hours and mixed with 20kg of cage layers droppings and 10kg of molasses. It was allowed to for 30 days, then sundried for 3 days and grinded before taking to the laboratory for other analysis. The total amount of feeds offered daily and representative samples were on weekly basis and pooled together after the experiment. The quantity of feed provided and residue of each day was weighed to determine the feed intake of individual animal. The initial body weights of the goats were taken at commencement of the experiment and subsequently at 7 days interval in the morning before feeding.

Experimental diet

Three experimental diets were formulated with the inclusion of the three different types of supplements on cassava peel which include the cassava peel + molasses + cage layer droppings. T1 indicates 0% treated cassava peel replacement, T2 indicates 25% replacement of maize with treated cassava peel, and, T3 indicates the replacement of maize with 50% of treated cassava peel.

Table 1: Experimental diet with different inclusion level of treated cassava peel with urea-molasses ensiled with cage layer droppings on West Africa dwarf goat.

Ingredients (kg)	Treatment 1 0%replacmet of cassava peel	Treatment 2 25% replacement of cassava peel	Treatment 3 50% replacement of cassava peel
Maize	28	21	14
Treated cassava peel	0	7	14
GNC	18	18	18
Corn bran	21	21	21
TSH	28	28	28
Limestone	2	2	2
Salt	1	1	1
Urea	1	1	1
Vitamin premix	1	1	1
Cp	15.90	15.95	15.99
Total	100	100	100

Collection of parameters

Immune function was assessed by quantifying immunoglobulin classes (IgA, IgG, and IgM), also using Stanbio-specific kits per Elghalid et al. (2020).

Oxidative stress markers evaluated included triiodothyronine (T3), total antioxidant capacity (TAC), and the enzymatic activities of malondialdehyde (MDA), superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (GR), and cortisol. These were likewise analyzed using the aforementioned commercial kits and standardized methodologies.

Statistical analyses

Data on body temperature regulation, serum biochemical markers, immune function, oxidative stress parameters, and semen characteristics were analyzed using analysis of variance (ANOVA) under a completely randomized design, employing SPSS version 23.0. To determine statistically significant differences among treatment means, Duncan's multiple range test was applied, with significance set at $P \leq 0.05$.

Results and Discussions

Immune and oxidative stress responses of Yankassa rams fed diets containing urea-molasses treated cassava peel ensiled with caged-layer droppings

Table 2 presents the immunological and oxidative stress responses of Yankassa rams fed diets incorporating urea-molasses treated cassava peels ensiled with caged-layer droppings. Across all treatment groups—including 25% (T2) and 50% (T3) dietary replacements—there were no significant differences ($P > 0.05$) observed in key immune markers, such as immunoglobulins G, A, and M, or in the metabolic hormone triiodothyronine (T3), when compared to the control group. Similarly, oxidative stress biomarkers, including superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (GR), and total antioxidant capacity (TAC), were unaffected by the dietary treatments. Moreover, stress indicators such as malondialdehyde (MDA) and cortisol concentrations also remained statistically unchanged ($P > 0.05$) across the different dietary inclusions.

Immunoglobulins—namely IgG, IgA, and IgM—are essential components of the adaptive immune system that contribute to host defense by neutralizing pathogens, blocking toxins, and preventing microbial adherence to mucosal surfaces (Woof & Kerr, 2005; Anaso et al., 2025a). The lack of significant variation in immunoglobulin levels across treatment groups suggests that the inclusion of the ensiled cassava peels did not compromise immune functionality.

Similarly, triiodothyronine (T3), a key thyroid hormone that governs metabolic activity, thermoregulation, and overall physiological stability (Bowen, 2010), was not altered by the test diets, indicating that basal metabolic functions remained intact.

Malondialdehyde (MDA), a marker for lipid peroxidation and oxidative membrane damage, remained stable across treatments, reflecting no apparent increase in oxidative stress levels. The unaltered MDA levels imply that the diets did not elicit excessive production of free radicals or compromise lipid integrity (Anaso et al., 2025a).

Cortisol, a glucocorticoid hormone released in response to physiological stress or hypoglycemia, also remained unchanged, highlighting the absence of stress-inducing effects from the experimental diets and suggesting good adaptation by the animals to the feed composition (Howhn & Marieb, 2010; Anaso, 2023a, 2023b).

Superoxide dismutase (SOD), a critical antioxidant enzyme that catalyzes the dismutation of superoxide radicals into oxygen and hydrogen peroxide, was not significantly affected, suggesting that no additional oxidative challenge was imposed by the diets. The stability of SOD activity further implies adequate micronutrient availability required for optimal enzymatic function (Ashour et al., 2014).

The activities of glutathione-dependent enzymes—glutathione peroxidase (GPx) and glutathione reductase (GR)—also remained consistent among treatment groups. These enzymes play indispensable roles in mitigating oxidative damage and maintaining redox balance by neutralizing reactive oxygen species (ROS) and preserving the functional integrity of biomolecules (Anaso et al., 2025a). Their unchanged activity supports the conclusion that the test diets did not disrupt intracellular antioxidant defense mechanisms.

Additionally, enzymes such as CAT, GPx, and GR, which collectively serve to neutralize hydrogen peroxide and other peroxides, showed no significant differences among groups. These enzymes are vital for protecting cellular structures by catalyzing the breakdown of hydrogen peroxide into water and oxygen, thereby mitigating potential oxidative injury (Chelikani et al., 2004; Deponte, 2013).

In summary, the incorporation of urea-molasses treated cassava peels ensiled with caged-layer droppings at up to 50% dietary replacement did not adversely affect immunological function, oxidative stress parameters, or systemic physiological stability in Yankassa rams. These findings reinforce the potential of this alternative feed resource as a safe and nutritionally viable component in small ruminant diets.

Table 2. Immune and oxidative stress responses of experiment animals

Parameter	T1	T2	T3	SEM
Immunoglobulin G (mg/100ml)	4001.67	3996.67	3965.33	23.29
Immunoglobulin A (mg/ml)	0.41	0.38	0.37	0.00
Immunoglobulin M (mg/ml)	4.07	3.96	3.92	0.06
Triiodothyroxine (nmol/L)	2.10	1.99	1.96	0.05
Melanodialdehyde (nmol/L)	0.50	0.52	0.56	0.02

Superoxide dismutase (nmol/mL)	1001.67	997.00	994.00	3.20
Catalase (U/gHb)	2001.33	1999.00	1996.00	2.23
Glutathione peroxidase (U/gHb)	203.00	198.33	195.33	2.96
Cortisol (ng/ml)	9.99	10.30	10.37	0.42
Total antioxidant capacity (nmol)	1.28	1.13	0.99	0.27
Glutathione reductase (IU/10^{11}RBC)	1.81	1.78	1.75	0.03

Means in the same row are statistically different at ($P<0.05$), T1 indicates 0% treated cassava peel replacement, T2 indicates 25% replacement of maize with treated cassava peel, and, T3 indicates the replacement of maize with 50% of treated cassava peel, SEM: indicate standard error of the mean

Conclusion

The result shows that animals fed with 25% and 50% replacement of urea-molasses treated cassava peel ensiled with caged layer droppings showed no significant difference in the heart rate, respiratory rate, earlobe temperature and rectal temperature when compared with that of the control diet. It can be concluded that the different treatments had no effect on the physiology of the animals. The result shows that animals fed with 50% replacement of urea-molasses treated cassava peel ensiled with caged layer droppings gave the highest semen motility, semen live, semen concentration, semen volume, scrotal length, scrotal circumference and libido. It can be concluded that the feed containing 50% replacement of urea-molasses treated cassava peel ensiled with caged layer droppings is best for the animals as it falls within general recommended ranges.

References

Anaso, E.U., Olafadehan, O.A., Chibuogwu, I.C., Alagbe, J.O. (2024a) Seminal morphology and organ morphometrics of rabbit bucks fed Piliostigma thonningii essential oil supplemented diet. *Sci Lett*. 2024;12(2):70–5. doi:10.47262/SL/12.2.132024280.

Anaso, E.U., Olafadehan, O.A., Chibuogwu, I.C., Shoyombo, A.J., Mailafia, S., Anaso, J.N., Fidelis, E.S. (2024d). Haematological profile and fertility potential of rabbits supplemented with Camel's Foot (Piliostigma thonningii) essential oil-based diet. *Turk J Agric Food Sci Technol*. 2024;12(12):2470–7. https://doi.org/10.24925/turjaf.v12i12.2470-2477.6870

Anaso, E.U., Olafadehan, O.A., Chibuogwu, I.C. (2025b). Nutrient digestibility, growth performance, cecal microbial profile, and fermentation characteristics of rabbit bucks fed Piliostigma thonningii essential oil supplemented diet. *Biotechnol Anim Husb*.;41(1):37–55. doi:10.2298/BAH2302205K.

Anaso, E.U., Olafadehan, O.A., Chibuogwu, I.C. (2025a). Nutritive effects and physiological responses of rabbits supplemented with Camel's Foot (Piliostigma thonningii) essential oil-based diet. *Vet Arhiv*.. doi:10.24099/vet.arhiv.2669.

Anaso, E.U., Olafadehan, O.A., Chibuogwu, I.C. (2023). Semen characteristics of rabbits fed Camel's Foot (Piliostigma thonningii) essential oil supplemented diet. *Discovery*. 2023;59:e36d1037.

Anaso, E.U., Olafadehan, O.A., Emeka, F.S. (2024c). Carcass and meat quality of rabbits supplemented with Camel's Foot (Piliostigma thonningii) essential oil-based diet. *Arch Zootech*. 2024;27(2):36–51. doi:10.2478/azibna-2024-0013.

Anaso, E.U., Olafadehan, O.A., Oluwafemi, R.A. (2021b). Biodegradation of agro-industrial by-products as a panacea to feed scarcity in Nigeria amidst farmer insecurity and global pandemic. *Proc 46th Annu Conf Niger Soc Anim Prod*. 2021;616–20.

Anaso, E.U., Olafadehan, O.A., Shoyombo, A.J., Emeka, F.S. (2024b). Body weight, scrotal parameters, and semen characteristics of Kano Brown bucks fed Pleurotus ostreatus solid-state fermented sugarcane scrapings. *Turk J Food Agric Sci*. 2024. doi:10.53663/turjfas.1486383.

Anaso, E.U., Olafadehan, O.A., Shoyombo, A.J. (2021a). Semen characteristics of Kano Brown bucks fed white rot fungi (Pleurotus ostreatus) biodegraded sugarcane scrapings-based diets. *Proc 46th Annu Conf Niger Soc Anim Prod*. 2021;625–8.

Anaso, E.U., Olafadehan, O.A. (2025). Pleurotus ostreatus biodegraded sugarcane scrapings: nutritive value, feed intake, and blood profile of buckling goats. *Arch Zootech*. 2025. 28:1, 61-76, 2025 DOI: 10.2478/azibna-2025-0004.

Anaso, E.U., Salihu, A.M. (2025). Identification and antimicrobial susceptibility of Pseudomonas aeruginosa strain PAO1 isolated from African catfish skin scrapings. *Sci Lett*. 2025;13(1):1324350sl. doi:10.47262/SL/13.1.132024350.

Anaso, E.U. (2023a). Bioactive compounds of Piliostigma thonningii essential oil detected by gas chromatography-mass spectrometry. *EJABS*. 2023;3(2):68–72.

Anaso, E.U. (2025b). Body thermoregulatory adaptation and blood metabolic profile of rabbits supplemented with Rolfe (Daniellia oliveri) leaf extract-based diet. *Science Letters* 2025;13(2):1325130sl

Anaso, E.U. (2025c) Immune status, reproductive potential, caecal microbial and fermentative characteristics of rabbits supplemented Rolfe (Daniellia oliveri) leaf extract essential oil based diet. *Discov Sci*. 2025. In press.

Anaso, EU. (2023b). Phytogenics and essential oil supplementation in rabbit and monogastrate production: a panacea to improved animal production and antibiotic resistance challenge in Nigeria. *EJABS*. 2023;3(2):45–51.

Anaso, E.U. (2025a). Body Thermoregulatory Adaptations and Reproductive Potentials Of Yankassa Rams Fed Diets Containing Urea-Molasses Treated Cassava Peel Ensiled with Caged-Layer Droppings. *4th international Congress of Turkish Journal of Agriculture-Food Science and Technology*. 1120-1126.

Ashour, E.A., Alagawany, M., Reda, F.M., Abd El-Hack, M.E. (2014). Effect of supplementation of Yucca schidigera to growing rabbit diets on growth performance, carcass characteristics, serum biochemistry and liver oxidative status. Asian J Anim Vet Adv. 2014;9:732–42.

Bowen, R. (2010). Physiologic effects of thyroid hormones. Fort Collins (CO): Colorado State University; 2010.

Chelikani, P., Fita, I., Leewan, P.C. (2004). Diversities of structures and properties among catalases. *Cell Mol Life Sci*. 2004;61(2):192–208.

Deponte, M., (2013). Glutathione catalysis and the reaction mechanisms of glutathione-dependent enzymes. *Biochim Biophys Acta*. 2013;1830(5):3217–66.

Elghalid, O.A., Kholif, A.E., El-Ashry, G.M., Matloup, O.H., Olafadehan, O.A., El-Raffaa, A.M., AbdEl-Hadya, A.M. (2020). Oral supplementation of the diet of growing rabbits with a newly developed mixture of herbal plants and spices enriched with special extracts and essential oils affects their productive performance and immune status. Livest Sci. 2020;238:104082.

FAO, (2001). Slaughter of livestock. Guidelines for human handling transport and slaughter of livestock. Heinz, G and Svicuvan, T(ed) Food and Agricultural Organization of the United Nation Rome, Italy.

Oboh, G. (2006). Nutrient enrichment of cassava peels using a mixed culture of Saccharomyces cerevisae and Lactobacillus spp. Solid media fermentation. *Electronic Journal of Biotechnology*, 9(1): 46 –49.

Olafadehan, O.A., Anaso, E.U., Shoyombo, A.J., Okunade, S.A. (2023a). Body thermoregulation and serum metabolic profile of Kano Brown bucks fed *Pleurotus ostreatus* biodegraded sugarcane scrapings. *Biotechnol Anim Husb*. 2023;39(1):61–72. doi:10.2298/BAH2202081R

Olafadehan, O.A., Gero, A., Okunade, S.A., Kholif, A.E., Adewuyi, P.A., Shoyombo, A.J., Anaso, E.U. et al. (2023b). Partial substitution of concentrate with *Parkia biglobosa* foliage improves feed utilization and performance of goats. *Arch Zootech*. 2023;26(2):83–95. doi:10.2478/azibna-2023-0016

Olafadehan, O.A. (2011). Change in haematological and biochemical diagnostics parameters of Red Sokoto goats fed tannin rich Pterocarpus erinaceus forage diets. *Veterinarski Arhiv* 4: 471- 483.

Woof, M.J., Kerr, M.A. (2005). Functions of immunoglobulin A in immunity. *J Pathol*. 2005;208(2):270–82.

Application of Artificial Intelligence Technologies in Livestock Management

Hatice Dilaver[1], Kamil Fatih Dilaver[2]

[1]Department of Economics and Law, Eurasian Studies Institute, Ömer Halisdemir University, Niğde,Türkiye
[2]Department of Electrical and Electronics Engineering, Faculty of Engineering, Ömer Halisdemir University, Niğde, Türkiye

Abstract

Artificial Intelligence (AI) has emerged as a transformative force in precision livestock farming. This paper presents a comprehensive analysis of AI subfields—Machine Learning (ML), Deep Learning (DL), Artificial Neural Networks (ANN), Computer Vision (CV), Robotics, and Natural Language Processing (NLP)—and their applications in livestock management. Key innovations include early disease detection, estrus prediction, behavior analysis, and personalized feeding strategies. A simulation using a Multilayer Perceptron (MLP) model in Python is also included, estimating milk yield from biometric features such as heart rate and eye temperature. Findings highlight AI's potential for improving productivity, animal welfare, and sustainability.

Key Words: *Artificial Intelligence, Livestock, Neural Networks, Deep Learning, Smart Farming*

Introduction

Artificial Intelligence (AI) is revolutionizing livestock management through data-driven approaches that improve productivity, efficiency, and animal welfare. Rooted in disciplines such as logic, computation, and neuroscience, AI technologies are now widely used for monitoring livestock behavior, health, and productivity. This paper explores AI's historical evolution, fundamental subfields, and cutting-edge applications in animal farming.

Materials and Methods

This study uses a multi-method approach: a systematic literature review, case study analysis, and a simulation model. The simulation employs a Multilayer Perceptron (MLP) neural network trained on synthetic biometric data (heart rate, respiratory rate, body temperature, and eye temperature) to predict milk yield in dairy cows.

Results and Discussion

The ANN model showed a Mean Squared Error (MSE) of 7.85 and Mean Absolute Error (MAE) of 1.99 liters in milk yield prediction. Although the R^2 value was negative due to data limitations, the model confirmed that biometric inputs can predict milk yield trends. AI applications like facial recognition, emotion detection, and behavior monitoring were also discussed. These tools enable early diagnosis and improve animal welfare and operational efficiency.

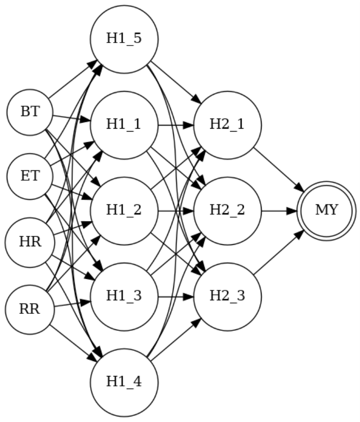


Figure 1. Multilayer Perceptron (MLP) Neural Network Architecture

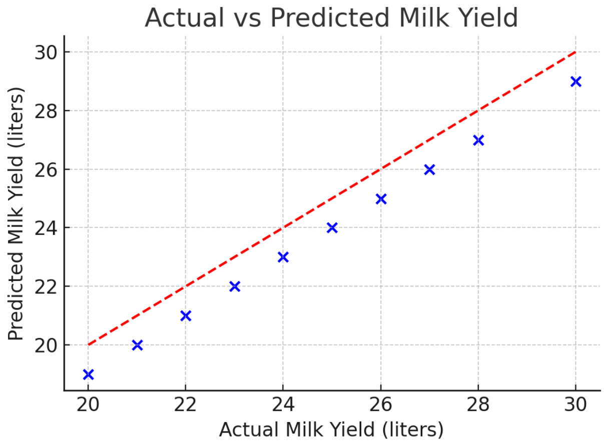


Figure 2. Actual vs Predicted Milk Yield

Acknowledgements
The authors would like to thank Ömer Halisdemir University for its academic support.

References

Andrew, W., Gao, J., Mullan, S., Campbell, N., Dowsey, A. W., & Burghardt, T. (2021). Visual identification of individual Holstein-Friesian cattle via deep metric learning. Computers and Electronics in Agriculture, 185, 106133.

Fuentes, S., Gonzalez Viejo, C., Cullen, B., Tongson, E., Chauhan, S. S., & Dunshea, F. R. (2020). Artificial intelligence applied to a robotic dairy farm to model milk productivity and quality. Sensors, 20(10), 2975.

Optimizing Deficit Irrigation Strategies for White Cabbage under Semi-Arid Conditions Using the TAGEM-SUET Model

Ali Kaan Yetik[1]

[1]Department of Biosystems Engineering, Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University, Niğde, Turkey

Abstract

Efficient irrigation management is critical for sustainable agricultural productivity in semi-arid regions facing increasing water scarcity. This study evaluated the effects of different irrigation scenarios (100%, 66%, 33%, and 0% of ETc) on white cabbage (*Brassica oleracea var. capitata*) cultivation under the semi-arid climatic conditions of Niğde, Türkiye, using the TAGEM-SUET irrigation scheduling model. The seasonal crop evapotranspiration (ETc) was estimated using 30-year historical climate data and the standardized FAO-56 Penman-Monteith equation embedded within TAGEM-SUET. Relative yield reductions, relative water-use efficiency (rWUE), and relative irrigation water-use efficiency (rIWUE) were calculated to quantify cabbage responses to water stress. Results indicated ETc at 428.7 mm, with actual evapotranspiration (ETa) declining significantly under deficit irrigation, resulting in proportional yield reductions from 100% (full irrigation) to 18% (rainfed). Moderate water deficits improved rWUE slightly (from 0.23% to 0.24% yield per mm water consumed), whereas rIWUE markedly increased under moderate deficit conditions (66% ETc), achieving 0.29% yield per mm irrigation applied. Rain-fed conditions drastically reduced both efficiency indicators due to substantial yield losses. Comparison with previous studies confirmed these results, highlighting the progressive yield reductions under increasing drought severity, while indicating that moderate deficit irrigation may be applied with tolerable yield loss. The findings suggest moderate deficit irrigation (66% ETc) as an optimal irrigation strategy for balancing water conservation and acceptable yield levels in semi-arid climates.

Key Words: *Deficit irrigation, Tagem-SUET, Water stress, White cabbage*

Introduction

Water scarcity and drought stress represent two of the most critical challenges affecting agricultural productivity globally (FAO, 2020). Particularly, regions characterized by semi-arid climates such as Niğde province in Central Anatolia, Türkiye, are increasingly vulnerable due to limited precipitation and uneven distribution of rainfall throughout the year. Under such circumstances, achieving optimal irrigation scheduling becomes essential for sustainable agricultural production and efficient utilization of water resources (Irik and Kirnak, 2022; Karaer et al., 2024).

Brassica oleracea var. capitata (white cabbage), an economically significant crop in Türkiye, is highly dependent on adequate irrigation due to its shallow rooting depth. Niğde ranks among the leading regions for cabbage cultivation, contributing substantially to the vegetable production of Türkiye (TURKSTAT, 2025). However, cabbage cultivation requires substantial seasonal water inputs, often exceeding local precipitation, necessitating supplemental irrigation to ensure adequate yield (Beshir, 2017).

Crop evapotranspiration (ETc) provides a reliable indicator of crop water demand and forms the basis of precision irrigation management. ETc is conventionally estimated using reference evapotranspiration (ETo) multiplied by crop-specific coefficients (Kc) (Allen et al., 1998). Among various methods, the FAO-56 Standardized Penman-Monteith equation is widely recognized as the most accurate and robust technique for estimating ETo, particularly when comprehensive meteorological data sets are available (Pereira et al., 2015; Deveci et al., 2025; Zhang, 2025).

Recently, digital decision-support tools have been developed to facilitate precise irrigation scheduling, enhancing water use efficiency and reducing yield losses associated with water stress. One such tool is TAGEM-SUET, a decision-support platform developed by the General Directorate of Agricultural Research and Policies (TAGEM) in Türkiye. TAGEM-SUET utilizes extensive long-term meteorological databases (30-year historical climate data), providing standardized evapotranspiration (ETo and ETc) estimations, crop water requirements, irrigation scheduling, and system design recommendations (TAGEM, 2025). Although TAGEM-SUET does not explicitly simulate crop yield, it can effectively assist in determining crop water stress levels and associated yield losses when integrated with crop yield response factors (Ky) as described by FAO (Doorenbos and Kassam, 1979).

Water Use Efficiency (WUE), defined as the ratio of marketable yield to total evapotranspiration, and Irrigation Water Use Efficiency (IWUE), defined as the ratio of yield to irrigation water applied, are critical indicators of water productivity under limited water scenarios (Howell, 2001; Kuşçu et al., 2013). Evaluating WUE and IWUE provides insights into how effectively irrigation water and overall water resources are converted into biomass or economic yield (Steduto et al., 2012).

Therefore, a comprehensive evaluation of crop water requirements and irrigation performance indicators is essential for developing site-specific, resource-efficient irrigation strategies. In this context, the present study aims to assess the effects of irrigation deficit scenarios on water consumption, yield loss, and water use efficiency in white cabbage cultivation under semi-arid conditions of Niğde using the TAGEM-SUET decision-support tool.

Materials and Methods

Study Site

This study was conducted in Niğde province, located in Central Anatolia, Türkiye (approximate latitude 37°58'N, longitude 34°40'E, elevation 1250 m). Niğde has a semi-arid climate characterized by hot, dry summers and cold winters. The long-term annual average precipitation is approximately 343 mm, concentrated primarily during winter and spring months, while summers remain distinctly dry. Average annual temperature is around 11 °C, with mean summer temperatures reaching up to 22 °C (TSMS, 2025).

The soil texture was defined as clay loam (CL), based on the global soil classification provided by the Harmonized World Soil Database (HWSD) (FAO, 2012). The effective rooting depth was assumed to be 90 cm, divided into three soil layers (0–30 cm, 30–60 cm, 60–90 cm). Field capacity (FC) values across the profile ranged from 0.31 to 0.33 m^3/m^3, and permanent wilting point (PWP) ranged from 0.16 to 0.18 m^3/m^3. The initial soil moisture was set to 80% of available water content, and an average infiltration rate of 10 mm h^{-1} was assumed based on typical values for clay loam soils.

TAGEM-SUET Decision Support Tool

The irrigation scheduling in this study was conducted using the TAGEM-SUET digital decision-support tool developed by the General Directorate of Agricultural Research and Policies (TAGEM), Ministry of Agriculture and Forestry, Türkiye. TAGEM-SUET incorporates 30-year historical meteorological data and calculates irrigation requirements by estimating reference evapotranspiration (ETo), crop evapotranspiration (ETc), actual evapotranspiration (ETa), net irrigation water needs, and seasonal water use volumes. It employs the standardized FAO-56 Penman-Monteith equation (Allen et al., 1998) to estimate ETo, which is then multiplied by crop-specific coefficients (Kc) to determine ETc. The TAGEM-SUET model has previously been employed in various studies for irrigation scheduling and water resource assessments across different regions and crops in Türkiye (Altınbilek and Kızıl, 2024; Gültaş et al., 2025).

TAGEM-SUET does not directly predict absolute crop yield. Instead, it provides a yield-loss estimation based on crop yield response factors (Ky), originally defined by Doorenbos and Kassam (1979). This factor relates relative yield decrease (1 – Ya/Ym) to relative evapotranspiration deficit (1 – ETa/ETc):

$$\left(1 - \frac{Y_a}{Y_m}\right) = k_y\left(1 - \frac{ET_a}{ET_c}\right)$$

Where; Ya is actual yield under deficit irrigation conditions, Ym is maximum yield achievable with full irrigation (100% ETc), ETa is actual evapotranspiration under deficit irrigation conditions, ETc is potential (seasonal) crop evapotranspiration without water stress, ky is the crop yield response factor of the crop. In this study, seasonal Ky for white cabbage was taken as 0.95 (Doorenbos and Kassam, 1979), indicating an almost proportional relationship between relative yield loss and relative evapotranspiration reduction. Although this value is widely used in simulation studies, some field experiments have reported Ky values exceeding 1.0, suggesting higher sensitivity of cabbage yield to water deficit under specific environmental or management conditions (Ayas, 2021).

Plant Material

White cabbage (*Brassica oleracea var. capitata*) was selected as the crop of interest due to its economic importance in Central Anatolia. In accordance with common agronomic practices in the region, transplanting was assumed to occur on July 1, 2025. Crop growth stages and corresponding crop coefficients (Kc values) were defined based on phenological development phases and were entered into the TAGEM-SUET interface, as given in Table 1.

Table 1. Crop Parameters for White Cabbage Entered into TAGEM-SUET

Parameter	Value	Description
Transplanting Date	1st of July	Beginning of crop development in the simulation
Stage I Duration	40 days	Initial stage
Stage II Duration	65 days	Development stage
Crop Coefficient (Kc1)	0.49	Kc value for the Stage I and Stage II
Stage III Duration	55 days	Mid-season stage
Crop Coefficient (Kc2)	1.04	Kc value for Stage III

Stage IV Duration	15 days	Late-season stage
Crop Coefficient (Kc3)	0.93	Kc value for Stage IV
Initial Rooting Depth	0.15 m	Starting effective rooting depth
Maximum Rooting Depth	0.80 m	Maximum rooting depth reached by the crop
Seasonal Yield Response Factor (Ky)	0.95	Indicates yield sensitivity to evapotranspiration deficit

Irrigation Scenarios
To evaluate the effects of water deficits on white cabbage performance, four irrigation scenarios were defined based on different fractions of ETc: 100% (full irrigation, S100), 66% (moderate deficit, S66), 33% (severe deficit, S33), and 0% (rainfed, S0). All scenarios were simulated using the TAGEM-SUET model, which utilizes a soil water balance approach to estimate irrigation scheduling and requirements. The irrigation method was set as drip irrigation, with key system parameters defined as follows: the fraction of total available water permitted for depletion (Ry) was set at 0.30, irrigation application efficiency was assumed to be 90%, and the wetted area fraction was specified as 80%. These values were used consistently across all irrigation scenarios to standardize system assumptions and isolate the effects of irrigation amount.
Calculation of Water Use Efficiency Indicators
Since absolute yield (in t ha^{-1}) was not simulated directly by the TAGEM-SUET model, yields were expressed as relative values (%), considering the full irrigation scenario (100% ETc) as 100%. Other scenario yields were computed proportionally based on relative yield loss estimates (Ky method).

$$rWUE = \frac{rY}{ET_a}$$

$$rIWUE = \frac{rY - rY_0}{I}$$

Where rY (%) refers to the yield of each treatment expressed as a percentage of the control (100%), rYo refers yield obtained from rain-fed treatment, ETa (mm) denotes the actual evapotranspiration during the growing season, and I (mm) represents the total amount of irrigation water supplied to each treatment. These relative indices enable the comparison of treatments on a per-unit-water basis and help distinguish the effects of irrigation strategies on yield performance independent of absolute yield values.

Results and Discussion

Seasonal Crop Water Use and Irrigation Requirements
The seasonal ETc simulated by the TAGEM-SUET model remained constant at 428.7 mm across all scenarios (Table 2). However, as irrigation was progressively restricted (from 100% to 0% ETc), actual evapotranspiration (ETa) significantly declined, indicating pronounced water stress effects. Under full irrigation (100% ETc), ETa matched ETc (428.7 mm), reflecting optimal water conditions. Conversely, ETa values fell to 354.3 mm (66% ETc), 254.1 mm (33% ETc), and ultimately 150.8 mm (rainfed conditions).

Table 2. Seasonal water balance and relative yield for white cabbage under four irrigation scenarios.

Parameter	S100	S66	S33	S0
ETc (mm)	428.7	428.7	428.7	428.7
ETa (mm)	428.7	354.3	254.1	150.8
Net Irrigation (mm)	300.4	201.3	102.1	0
Total Irrigation (mm)	337.9	226.4	114.9	0
Relative Yield (%)	100	84	61	18

As expected, reducing irrigation significantly decreased net irrigation depth from 300.4 mm (100% ETc scenario) to 0 mm under rainfed conditions (Table 2). The substantial reduction in ETa under limited irrigation highlights the critical water stress conditions induced by deficit irrigation scenarios. The water use outcomes observed in this study align well with established values from prior research. Globally, seasonal water requirements for cabbage typically range from about 380 to 500 mm, depending on climate and growing season length. This model-simulated full irrigation evapotranspiration (ETc) of 428.7 mm falls squarely within this range, lending confidence that the estimations are realistic. In fact, similar magnitudes of water use have been reported under Mediterranean semi-arid conditions: for example, Erken and Yildirim (2019) found that providing approximately 411 mm of irrigation water over the season was necessary to maximize white cabbage yields. In this case, the 100% ETc treatment corresponded to a net irrigation depth of 300.4 mm (with the remainder of ETc met by effective rainfall), giving a total water supply on the order of 430 mm, a value in close agreement with those literature reports for optimal

production. This consistency suggests that fully irrigated scenario achieved a crop water supply near the upper end of cabbage water needs for the region, as intended.
Reducing irrigation showed a pronounced effect on actual crop water use (ETa), a trend corroborated by previous studies. In a two-year field experiment, seasonal irrigation amounts ranging from 0 up to 620 mm led to total cabbage ET between roughly 150 mm (rainfed) and 700 mm (fully irrigated) (Agrawal et al., 2018). The findings mirror this pattern: in this study only 150.8 mm of ETa (essentially the utilization of seasonal rainfall) were observed under rain-fed conditions, whereas full irrigation achieved 428.7 mm of ET, with intermediate treatments in between. This indicates that cabbage evapotranspiration is tightly constrained by available water when water is limited, the crop simply cannot evaporate/transpire at its potential rate, leading to water stress. Notably, the 66% ETc deficit treatment in this study still attained an ETa of 354 mm (about 83% of the maximum ETc), implying that moderate irrigation shortfalls can be partially buffered by soil moisture reserves or reduced soil evaporation. However, at the more severe deficit of 33% ETc, ETa dropped sharply to 254 mm (only 59% of maximum), underscoring that beyond a certain threshold of water reduction, cabbage experiences severe stress and dramatically curtailed water use. Erken and Yildirim (2019) support this threshold behavior: they reported that about 287 mm of seasonal irrigation was the minimum needed to conserve yield, whereas an irrigation amount around 168 mm was insufficient to prevent major yield losses. In other words, supplying roughly two-thirds to three-quarters of the full water requirement of crop might sustain acceptable yields, but more drastic cutbacks (on the order of one-third or less of full needs) cause disproportionate yield reduction. This aligns with the observations of steep ETa (and by extension yield) declines under the 33% ETc and rainfed scenarios. It is also important to consider how regional climate and irrigation methods influence these water use outcomes. The 428 mm ETc we obtained for optimally irrigated cabbage is characteristic of a temperate-Mediterranean growing season; in hotter or longer-season climates, water consumption can be substantially higher.
Cabbage is generally considered a shallow-rooted, water-demanding crop, and inadequate moisture during critical growth stages (especially head formation) can markedly reduce marketable yield and quality. The results are consistent with this understanding: when full crop evapotranspiration was satisfied (428.7 mm ETc), the crop could reach its potential, but any significant shortfall in water led to proportionate (and eventually severe) reductions in water use and presumably yield. Consequently, while cabbage can tolerate brief or mild drought, sustained irrigation deficits like those in the 33% ETc and rainfed scenarios resulted in pronounced water stress. These findings concur with the consensus of earlier studies that, despite moderate drought tolerance of cabbage, reliable irrigation is crucial for achieving optimal yields in most environments. By comparing these simulations with empirical results from the literature, it is confirmed that the water balance outputs of TAGEM-SUET model are realistic and that the deficit irrigation impacts it predicts reflect real-world crop responses. This comparative analysis strengthens the validity of conclusions on seasonal water requirements and provides context for developing irrigation strategies for white cabbage in water-limited regions.

Relative Yield Response under Water Deficit
The yield response to water stress was quantified by employing the seasonal crop yield response factor (Ky = 0.95). Relative yield (expressed as percent of maximum achievable yield) declined notably with increasing water deficit, from full yield (100%) under fully irrigated conditions, to 84%, 61%, and dramatically to 18% at 66%, 33%, and 0% ETc respectively (Table 2). In practical terms, the rain-fed yield was extremely low (only a small fraction of the irrigated yield), reflecting the severe growth limitation due to water shortage. These results vividly illustrate how progressively increasing water stress translates into pronounced yield reductions in cabbage. The dramatic collapse to 18% of maximum yield under non-irrigated conditions clearly indicates that cabbage is unsuitable for drought conditions, as residual soil moisture and rainfall alone are insufficient for meaningful yield. Numerous field studies corroborate the strong yield penalty from water deficits in cabbage. For example, Tiwari et al. (2003) found that providing about 400 mm of water via drip irrigation produced a maximum cabbage yield of 106 t/ha, whereas intentionally withholding 20-40% of that water caused yield to decline slightly to 101-105 t/ha. This relatively modest yield reduction under mild deficit suggests that cabbage can tolerate a small water shortfall with only minimal loss in production when other conditions are optimal. However, as water deficit becomes more severe, the yield impacts become much more pronounced. In a field experiment, fully irrigated plots (meeting 100% of ET demand) achieved about 80 t/ha of cabbage head yield under conditions of single season, whereas plots receiving no irrigation (rain-fed only) yielded only 19-35 t/ha, barely a quarter of the well-watered yield (Erken and Yildirim, 2019). This dramatic drop under rain-fed treatment underscores how inadequate rainfall can drastically curtail cabbage production. In addition, Erken and Yıldırım (2019) reported that supplying 70% of the water requirement of cabbage still produced a fairly high yield (74 t/ha), but completely stress conditions (0% irrigation) plummeted yields to below 20 t/ha in a drier year. These findings align with the notion that full irrigation is required to approach maximum yield potential, while significant deficits cause disproportionate losses in output. All these results from different regions consistently demonstrate that water stress causes a sharp decline in cabbage yield, even though the exact magnitude can vary with local environment and management practices.

In summary, the evidence from both the current study and prior research converges on the conclusion that water stress markedly suppresses cabbage productivity. Even a moderate reduction in available water can cause noticeable yield losses, and severe deficits are devastating to yield. To safeguard yield, growers should ensure timely and sufficient irrigation for cabbage, especially during critical growth stages (e.g. head formation) when the sensitivity of crop to water deficit peaks. In water-limited regions, deficit irrigation techniques might be employed to conserve water, but one must acknowledge the trade-off: any water savings will inevitably come at the cost of reduced yield. Therefore, identifying the threshold of tolerable yield reduction is key. Generally, keeping water stress below the 30% level (i.e. deficit not much more than 20–30% of full requirements) appears critical, since beyond that point cabbage yields decline significantly (Erken and Yildirim, 2019). Ultimately, improving drought resilience (through better irrigation management or breeding more drought-tolerant cultivars) remains vital for sustaining cabbage production under scenarios of increasing water scarcity. Ensuring an adequate water supply (in the right amount and at the right time) is fundamental to achieving near-maximum cabbage yields and maintaining quality under variable climate conditions.

Relative Water Use Efficiency Indices

Relative water-use efficiency (rWUE), reflecting percent yield produced per millimeter of ETa, slightly increased from 0.23% per mm under full irrigation (S100) to 0.24% per mm at S66 and S33 and then dropped significantly to 0.12% per mm under rainfed conditions (S0). In contrast, relative irrigation water-use efficiency (rIWUE) notably increased with decreasing irrigation supply, reaching its highest value (0.37% per mm) at S33 Although rIWUE improved notably, the associated severe yield losses suggest moderate deficit irrigation (S66) as the optimal scenario, effectively balancing yield loss and irrigation water savings in semi-arid conditions (Figure 1). This trend is consistent with findings in wheat and other crops, where the highest WUE is often obtained under mild to moderate water stress in semi-arid environments (Hafiza et al., 2015). The improvement in WUE at moderate deficit is primarily because yield is only marginally affected while water input is substantially reduced, meaning the crop produces nearly the same output with less water.

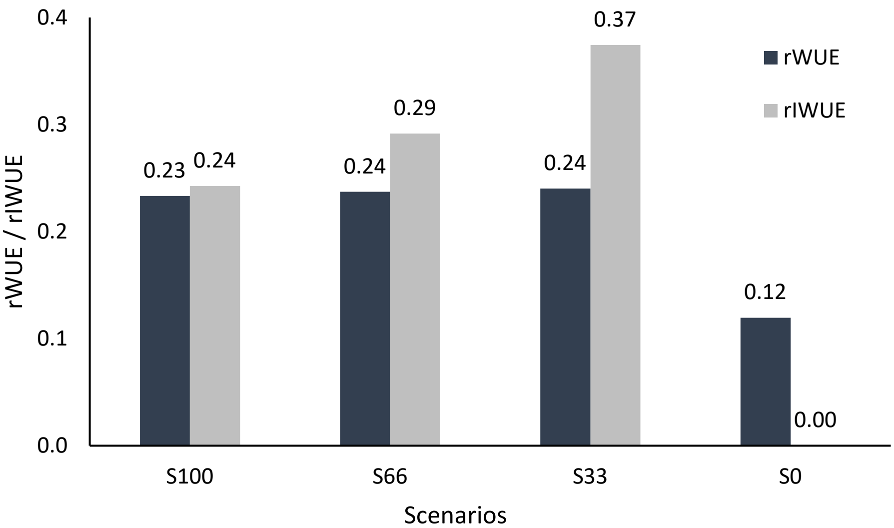


Figure 1. Relative efficiency indices under deficit irrigation scenarios

In contrast, severe water stress greatly diminishes yield and thereby reduces WUE. In the study, when irrigation was withheld entirely (rainfed conditions), relative WUE dropped sharply to 0.12% per mm, about half the value under full irrigation. This indicates that beyond a threshold of water deficit, the decline in yield is proportionally larger than the reduction in water use, causing WUE to deteriorate. Severe stress during critical periods (e.g. flowering and grain filling) can curtail grain formation and biomass accumulation, undermining the ability of crop to convert water into yield. Hafiza et al. (2025) observed that wheat is particularly sensitive to severe deficits during reproductive stages, which limits yield components and ultimately lowers WUE. Thus, while mild deficits can be tolerated or even beneficial for efficiency, extreme water limitation leads to diminishing returns: the crop consumes water (from soil moisture or minimal rainfall) for basic survival or maintenance, but produces very little harvestable yield, resulting in poor water productivity. The IWUE, on the other hand, tends to show a different pattern under deficit regimes because it considers only the applied irrigation water. As irrigation supply decreases, the yield obtained per unit of irrigation often increases, especially if the crop can utilize some stored soil moisture or rainfall. In the estimations, the relative IWUE rose markedly with greater water restriction – reaching a maximum of 0.37% yield per mm at the most stressed irrigation level (S33). This indicates that the irrigation water that was applied was used very productively, yielding more output per millimeter of irrigation than at higher water inputs. Such a result is commonly reported: deficit irrigation almost always raises IWUE, since any given yield is achieved with less irrigation water. Harisha et al. (2024) similarly found that reducing irrigation by 50% increased seed IWUE by over 20% in a semi-arid cropping system, reflecting more efficient use of the limited water. The physiological basis is that under water stress, crops may reduce luxury water use and focus on reproduction, so each unit of irrigation contributes relatively more to grain yield than under abundant water conditions. Additionally, there are simply fewer losses to runoff or deep percolation when smaller irrigation amounts are applied carefully (especially with drip irrigation). However, it is important to balance water savings with yield objectives. The highest IWUE in this study occurred at a severe deficit (S33), but this came at the cost of a drastic yield reduction. This trade-off is well documented: although maximizing IWUE (or WUE) under heavy water restriction can indicate efficient water use, it often coincides with significant yield penalties that may not be acceptable to farmers.

Responses of White Cabbage to Water Stress

Yield losses observed under water-deficit conditions can be attributed to critical physiological adaptations in cabbage. Water stress in cabbage, as in other Brassica species, initially triggers stomatal closure through enhanced abscisic acid (ABA) synthesis (Haghighi et al., 2020). Although this physiological mechanism conserves water by reducing transpiration rates, it concurrently limits CO_2 uptake, decreasing photosynthetic capacity and overall growth (Flexas and Medrano, 2002; Maggio et al., 2005). Furthermore, reduced leaf expansion and leaf area index under deficit irrigation conditions exacerbate the limitations on carbon assimilation, ultimately affecting biomass accumulation and yield formation (Kuşçu et al., 2013; Batool et al., 2023).

Cabbage, predominantly composed of water (90-95%), is particularly sensitive to water shortages during critical development stages, especially head formation (Wien and Wurr, 1997). The severe yield loss (82% yield reduction in rainfed conditions) observed here aligns with the literature highlighting vulnerability of cabbage to extended drought periods during vegetative and head-formation stages (Hara and Sonoda, 1982). Conversely, mild stress scenarios demonstrated the partial resilience of crop, maintaining considerable yield (84%) even at a moderate reduction in water supply (66% ETc). This resilience might be explained by physiological adaptation mechanisms of cabbage such as osmotic adjustment, increased root-to-shoot ratio, or enhanced antioxidant activities under moderate water stress (Haghighi et al., 2020).

Conclusions

This study assessed the responses of white cabbage to varying deficit irrigation scenarios under the semi-arid conditions of Niğde, Türkiye, using the TAGEM-SUET model. The simulations highlighted a clear and proportional decline in cabbage yield as irrigation water availability decreased, confirming vulnerability of cabbage to severe water stress. Under full irrigation, seasonal evapotranspiration (ETa) matched the potential crop evapotranspiration (ETc) of approximately 428.7 mm, maximizing yield. Moderate water deficits (66% ETc) improved relative water-use efficiencies (rWUE and rIWUE), suggesting more efficient use of water resources with minimal yield penalty. In contrast, severe deficit scenarios (S33 and S0) drastically reduced yield, negatively affecting overall water productivity. The comparative analysis with previous empirical studies validated these findings, demonstrating a consistent decline in yield under increasing water deficit conditions, particularly when stress occurred during critical growth stages. Consequently, moderate deficit irrigation, supplying roughly two-thirds of the crop water requirement, emerges as the recommended irrigation practice, effectively balancing yield preservation and water conservation. Future research should integrate field experiments to confirm model predictions and explore genotype-specific responses to drought, providing deeper insights for developing water-efficient irrigation strategies in semi-arid agriculture.

References

Agrawal, N., Tamrakar, S. K., Tripathi, M. P., & Tiwari, R. B. (2018). Response of cabbage under different levels of irrigation and fertigation through drip. Int. J. Curr. Microbial. App. Sci. Special, (6), 750-759.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome, 300(9), D05109.

Altınbilek, H. F., & Kızıl, Ü. (2024). Irrigation scheduling and determination of irrigation water requirement of paddy rice with drip irrigation using TAGEM-SUET model. Uludağ Üniversitesi Mühendislik Fakültesi Dergisi, 29(2), 347-358. https://doi.org/10.17482/uumfd.1470239

Ayas, S. (2021). Effect of Irrigation and Fertigation Levels on Cabbage (*Brassicaceae Oleracea var. capitata* L. Grandslam F1). Turkish Journal of Agriculture-Food Science and Technology, 9(2), 401-411. https://doi.org/10.24925/turjaf.v9i2.401-411.4134

Batool, M., El-Badri, A. M., Hassan, M. U., Haiyun, Y., Chunyun, W., Zhenkun, Y., ... & Zhou, G. (2023). Drought stress in Brassica napus: effects, tolerance mechanisms, and management strategies. Journal of Plant Growth Regulation, 42(1), 21-45. https://doi.org/10.1007/s00344-021-10542-9

Beshir, S. (2017). Review on estimation of crop water requirement, irrigation frequency and water use efficiency of cabbage production. Journal of Geoscience and Environment Protection, 5(07), 59. https://doi.org/10.4236/gep.2017.57007

Deveci, H., Önler, B., & Erdem, T. (2025). Modeling the Effect of Soil Type Change on Irrigation Water Requirements of Sunflower and Wheat Using CROPWAT 8.0. Water, 17(10), 1437. https://doi.org/10.3390/w17101437

Doorenbos J., & Kassam, A.H. (1979). Yield Response to Water. FAO Irrigation and Drainage paper No. 33, FAO, Rome, Italy, p. 193

Erken, O., & Yildirim, M. (2019). Yield and quality compounds of white cabbage (Brassica oleracea L. cv. Capitata) under different irrigation levels. Journal of Agricultural Science and Technology, 21(5), 1341-1352.

FAO. (2012). Harmonized World Soil Database (version 1.2). FAO. 42 pp

FAO. (2020). The state of food and agriculture 2020: Overcoming water challenges in agriculture. Rome: FAO

Flexas, J., & Medrano, H. (2002). Drought‐inhibition of photosynthesis in C3 plants: stomatal and non‐stomatal limitations revisited. Annals of botany, 89(2), 183-189. https://doi.org/10.1093/aob/mcf027

Gültaş, H. T., Ahi, Y., & Çakmak, B. (2025). Assessment of water resources status using the water footprint concept: The case of Tekirdağ province. Black Sea Journal of Agriculture, 8(2), 186-193. https://doi.org/10.47115/bsagriculture.1624100

Haghighi, M., Saadat, S., & Abbey, L. (2020). Effect of exogenous amino acids application on growth and nutritional value of cabbage under drought stress. Scientia Horticulturae, 272, 109561.

Hara, T., & Sonoda, Y. (1982). Cabbage-head development as affected by nitrogen and temperature. Soil Science and Plant Nutrition, 28(1), 109-117.

Harisha, C. B., Rane, J., Halagunde Gowda, G. R., Chavan, S. B., Chaudhary, A., Verma, A. K., ... & Reddy, K. S. (2024). Effect of deficit irrigation and intercrop competition on productivity, water use efficiency and oil quality of chia in semi-arid regions. Horticulturae, 10(1), 101. https://doi.org/10.3390/horticulturae10010101

Howell, T. A. (2001). Enhancing water use efficiency in irrigated agriculture. Agronomy journal, 93(2), 281-289. https://doi.org/10.2134/agronj2001.932281x

Irik, H. A., & Kirnak, H. (2022). Evaluation of spectral vegetation indices for drip irrigated pumpkin seed under semi-arid conditions. Arabian Journal of Geosciences, 15(9), 861. https://doi.org/10.1007/s12517-022-10136-z

Karaer, M., Gülümser, E., Kardeş, Y. M., Gültaş, H. T., Mut, H., & Arslan, O. (2024). Artificial neural network modeling for investigation on the effect of deficit irrigation and nitrogen levels on yield and quality of hay remaining after seed harvest of sorghum sudangrass hybrid. Communications in Soil Science and Plant Analysis, 55(17), 2565-2577. https://doi.org/10.1080/00103624.2024.2369201

Kuşçu, H., Karasu, A., Oz, M., Demır, A. O., & Turgut, İ. (2013). Effect of irrigation amounts applied with drip irrigation on maize evapotranspiration, yield, water use efficiency, and net return in a sub–humid climate. Turkish Journal of Field Crops, 18(1), 13-19.

Maggio, A., De Pascale, S., Ruggiero, C., & Barbieri, G. (2005). Physiological response of field-grown cabbage to salinity and drought stress. European journal of agronomy, 23(1), 57-67. https://doi.org/10.1016/j.eja.2004.09.004

Pereira, L. S., Allen, R. G., Smith, M., & Raes, D. (2015). Crop evapotranspiration estimation with FAO56: Past and future. Agricultural water management, 147, 4-20. https://doi.org/10.1016/j.agwat.2014.07.031

Shoukat Hafiza, B., Ishaque, W., Ahmad, S., Ali, S., & El-Sheikh, M. A. (2025). Optimizing wheat productivity and water productivity through deficit irrigation strategies in semi-arid environments. Scientific Reports, 15(1), 20630. https://doi.org/10.1038/s41598-025-04618-9

Steduto, P., Hsiao, T. C., Fereres, E., & Raes, D. (2012). Crop yield response to water (Vol. 1028, p. 99). Rome: fao.

TAGEM (2025). Türkiye Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü. https://www.tarimorman.gov.tr/TAGEM/Haber/843/Sulama-Yonetimi-VeBitki-Su-Tuketimi-Sistemi-Tagem-SUET-Ile-Tarimda-Su-Tasarrufu-Ve-Su-VerimliligineRehberlik-Ediyoruz. Access date: 16.06.2025.

Tiwari, K. N., Singh, A., & Mal, P. K. (2003). Effect of drip irrigation on yield of cabbage (Brassica oleracea L. var. capitata) under mulch and non-mulch conditions. Agricultural water management, 58(1), 19-28.

TSMS. (2025). Turkish State Meteorological Service, climate data of long-term period.

TURKSTAT. (2025) Turkish Statistical Institute. https://tuikweb.tuik.gov.tr/PreTablo.do?alt_id=1001. Accessed 3 June 2025

Wien, H. C., & Wurr, D. C. E. (1997). Cauliflower, broccoli, cabbage and Brussels sprouts. The physiology of vegetable crops.

Evaluation of Microbiological Quality of Minced Beef Meat Coated with Chitosan Containing Garlic Esential Oil During Refrigerated Storage

Maliha Afreen[1*], İlknur Uçak[2]

[1]University of Veterinary and Animal Science, Lahore, Pakistan
[2]Nigde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Department of Animal Production and Technologies, Nigde, Turkiye
[*]Corresponding Author email: malihaafreen120@gmail.com

Abstract

The human population needs high requirements of protein which could get from red meat including mutton and beef. Beef meat is more inclined to spoilage because of high water content, suitable substrate for microbial growth. Beef meat can be preserved to enhance their shelf life by using naturally derived preservatives like chitosan and essential oils in forming edible coatings. In this study we used chitosan coating with garlic essential oil emulsion to inhibit bacterial growth in minced beef meat. We divided minced beef meat into three groups, one with chitosan coating supplemented with 0.5% garlic essential oil (G0.5) and second with chitosan coating supplemented with 1% garlic essential oil (G1) and third group with chitosan coating is control group (C). After microbiological analysis it was found that the initial total psychrophilic bacteria count was 1.91log CFU/g in beef meat which increased to 7.04 log CFU/g in C group while 5.99 log CFU/g and 5.24 log CFU/g in G0.5 and G1 respectively at the end of storage. Total mesophilic bacteria count was 2.27log CFU/g at the beginning of storage which increased to 7.33, 6.07 and 5.44 log CFU/g in C, G0.5 and G1 respectively at the end of the storage. Similarly Total Enterobacteriaceae count was found to be 1.59 log CFU/g at the beginning of the storage, which increased to 4.77, 3.78 and 3.26 log CFU/g in the C, G0.5 and G1 respectively. These results presented that G1 has less bacterial growth overall which proves that 1% garlic essential oil with chitosan coating could be good for decreasing bacterial growth in minced beef meat products for long time preservation.

Keywords: *Microbial spoilage, chitosan coating, essential oil, shelf life*

Introduction

Conferring the continually expanding human population, the nutritional issues resulting from animal protein deficiencies are extremely important to humans. Consequently, red meat species have a significant part in human nutrition as an animal-based diet (Mehta et al., 2015). Due to their characteristics (a favorable substrate for microbes, a suitable pH, high water activity, unsaturated fatty acid content, etc.), red meats have a limited shelf life, which makes storage and transit difficult (Olivera et al., 2013). Therefore, it must be consumed and processed quickly; otherwise, the items will be subject to chemical, microbiological, and sensory spoiling. Chemical and microbiological spoils are more of a problem than the degradation of the sensory qualities, even if spoiling impacts sensory qualities including color changes and putrefaction (Devatkal et al., 2014).

Packaging technology is frequently utilized to preserve quality, prolong shelf life, and maintain cleanliness, particularly in foods that are susceptible to oxidative and microbiological spoiling (Ahmad et al., 2012). Edible coating materials have been employed in food preservation in recent years (Aydin et al., 2017). Natural resources are used to create thin-layered, non-synthetic packaging materials that are produced on the surface of food products and ingested with the meal. These materials regulate the passage of solids, gases, and moisture. Applying edible films or coatings on food's outside or in between layers helps extend its shelf life and shield it from the elements (Işık et al., 2013). Edible coatings are becoming more popular in the food business because of their low cost, minimal technical requirements, and effective preservation (Beikzadeh et al., 2020; Duran & Kahve, 2016).

Meanwhile beef naturally spoils quickly the process is complex and involves a combination of microbiological, chemical, and physical changes. The main reasons for foodborne diseases and shorter shelf lives in beef are microbial contamination and lipid oxidation during processing and storage (Rao et al., 2008). People are becoming increasingly conscious of the harmful health effects associated with the use of chemical preservatives, such as potassium sorbate, sodium nitrate, and benzoic acid. To prevent the oxidation of lipids and proteins, researchers and the food industry concentrate on the consumption of naturally derived products, such as chitosan (Latou et al., 2014), bacteriocins (Lorenzo et al., 2018; Karimaei et al., 2022), and essential oils (EOs) (Simona et al., 2021; Soltan Dallal et al., 2024). The quality and shelf life of food items can be improved by applying active edible coatings (Raji et al., 2019).

Deacetylation of chitin yields chitosan, which is one of the most significant edible coatings utilized globally (Abdou et al., 2008; Kuzgun & İnanlı, 2013). Applying chitosan, a polysaccharide-based coating, to food's exterior helps regulate its morphological, physiochemical, and physiological alterations (Duran & Kahve, 2016). According to Coma et al. (2002), chitosan films have antibacterial and antioxidant properties and can regulate the permeability of oxygen and moisture in food. Chitosan's polycationic characteristics give it an antibacterial action. In fact, because it interacts to neutralize negatively charged molecules, it works well against germs. At pH 6.3, the amine group of the glucose monomer of chitosan interacts electrostatically with negatively charged microbial cell membranes through its pKa value. As a result, the microbial membranes become less intact, which causes the inner and outer membranes to leak cell components (Helander et al., 2001; Liu et al., 2004).

The Food and Drug Administration (FDA) has designated essential oils (EOs) derived from natural sources as safe (GRAS), meaning they are generally safe for consumer consumption (Jackson-Davis et al., 2023). The fruits, buds, flowers, leaves, seeds, and roots of many plants can all provide these essential oils. As for their antibacterial qualities, EOs may be a suitable substitute for antibiotics (Calo et al., 2015; Karimaei et al., 2024). Thus, the increasing desire for natural food additives has led to a rise in the usage of EOs as potential alternative antimicrobials (Wi´nska et al., 2019). These secondary metabolites prevent food pathogens and spoilage bacteria from growing (de Silva et al., 2021). However, essential oils' stability during processing and storage is diminished by their hydrophobic and volatile characteristics as well as their susceptibility to light and oxygen. Furthermore, effective application levels are limited in direct applications due to the potential for essential oils to promote organoleptic degradation in meals. Thus, another method is to combine essential oils with edible coatings or films. Edible coatings become more stable and effective when emulsions made with essential oils are added (Ucak & Afreen, 2022; Renur et al., 2016; Ebadi et al., 2019; Ucak et al., 2021; Ucak et al., 2019). As a result, the primary goal of this research is to make an emulsion with garlic essential oil and then cover minced beef flesh with the resulting chitosan coating. It is said to prevent the growth of microorganisms in beef meat when it is being stored in the refrigerator.

Materials and Methods

Materials

Minced beef meat Garlic essential oil provided from local market in Niğde region.

Method

Preparation of chitosan coatings and application to minced beef meat samples

Chitosan solution was prepared as the prescribed method (Ojagh et al., 2010). Chitosan (Chitosan from shrimp shells, ≥75% -deacetylated chitin) used by mixing and stirring 1g of 2% chitosan (w/v) in 100ml of 1% acetic acid (v/v), aqueous solution at room temperature for 3 hours. To provide the solution plasticity, glycerol (0.75 ml/g) and 75% (w/w) chitosan were then added. The mixture was then stirred with a magnetic stirrer for 10 minutes at 95°C. Emulsions were made using Tween 80 at the same rate as 0.5% and 1% concentration of garlic essential oil, as established in early studies. The ultrathorax homogenizer was used to homogenize the emulsions for three minutes at 70°C and 13.500 rpm. After cooling to 55°C, the emulsion was left for some time to allow the gas bubbles to go.

Three groups were control group (C) without coating, chitosan coated groups supplemented with 0.5% (G0.5) and 1% (G1) concenteration of garlic essential oil were prepared. Every sample was shaped into small balls of 10g. After 30 seconds of soaking in the previously made chitosan solutions, the minced beef meat was left to stand for two minutes. They were then given another 30-second soak in the solution and given another 2-minute drying period (Ojagh et al., 2010). Every sample was wrapped in stretch film and placed on styrofoam plates. The control group consisted of one set of minced beef meat that was not covered with chitosan solution. Every group was stored on styrofoam plates and wrapped in stretch film. After every two days, quality analyses were performed on all samples which were kept at 4ºC±1 in a refrigerator.

Microbiological analysis

To perform microbiological investigations, a beef meatball sample of 10g was homogenized in 90ml of ringer solution. One ringer tablet was diluted in 500 milliliters of distilled water to create the ringer solution, which was then autoclaved, and nine milliliters were added to tubes to create serial dilutions. The smear culture technique was used for the counts of total mesophilic and total psychrophilic bacteria into Plate Count Agar media. The plates were incubated for two days at 30°C and for one week at 8–10°C correspondingly (Anonymous, 1998). Dilutions were inoculated into Violet Red Bile Agar (VRBA) medium using the bulk sowing method, and the samples were cultured for 24 to 48 hours at 37°C to determine the number of Enterobacteriaceae (Anonymous, 1998).

Statistical analysis

The data was compared using the Duncan multiple comparison test (one-way Anova at $P<0.05$ significance level) and statistical analyses were conducted using SPSS software (Statistical Analysis System, Cary, NC, USA).

Results and Discussion

Bacterial growth is one of the main causes of spoilage of meat and meat products. The effect of chitosan coating enriched with garlic essential oil emulsion on the total psychrophilic bacteria count in the minced beef meat is presented in figure 1. Significant differences ($P<0.05$) were observed between control group and chitosan coating treated groups with different concenterations of essential oil emulsions during the storage time. The initial total psychrophilic bacteria count was determined to be 1.91log CFU/g in beef meat. During the storage period, this value increased in all samples as control group has 7.04 log CFU/g while G0.5 and G1 have 5.99 log CFU/g and 5.24 log CFU/g respectively at the 10^{th} day of storage. It shows that control group has the highest bacterial growth while G1 group of chitosan coating with 1% garlic essential oil emulsion has strong antibacterial effect.

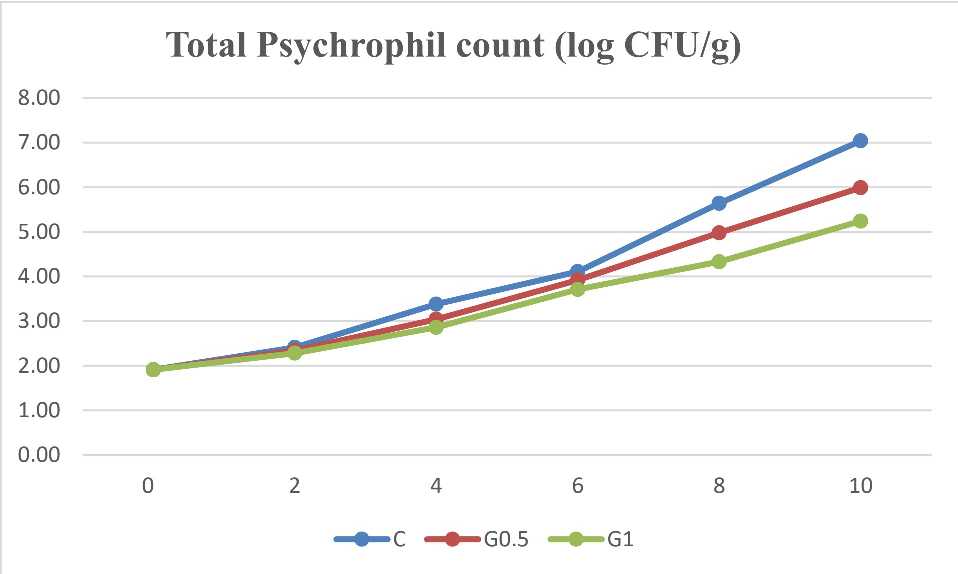


Figure 1. Changes in total psychrophilic bacteria count of minced beef meat during storage.

Total mesophilic bacteria count was 2.27log CFU/g in the minced beef meat at the beginning of storage. This number increased in all groups and control groups have the highest value of bacterial growth as 7.33 log CFU/g while G0.5 and G1 have 6.07 log CFU/g and 5.44 log CFU/g respectively at the end of the storage. The effect of chitosan coating enriched with garlic essential oil emulsion on the total mesophilic bacteria count in the minced beef meat is presented in figure 2.

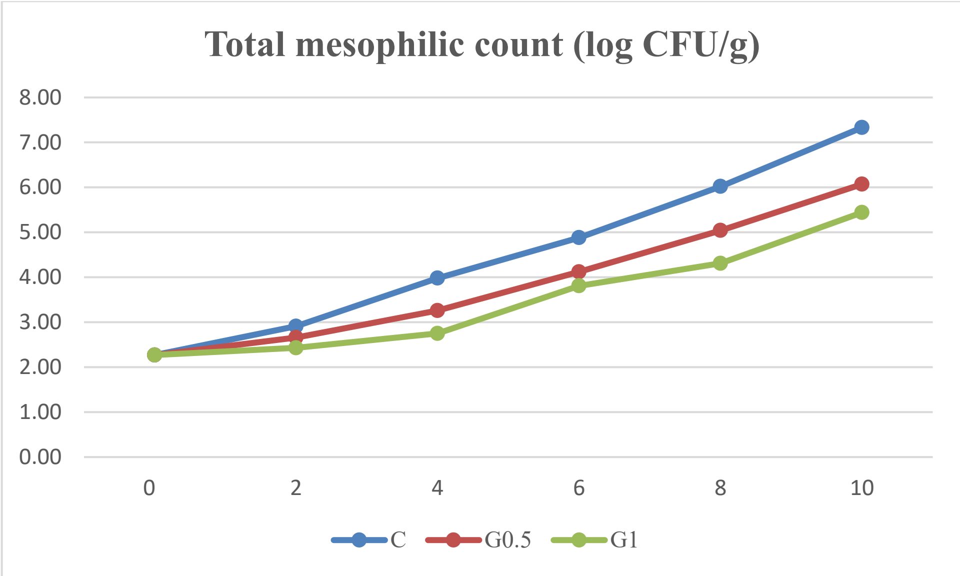


Figure 2. Changes in total mesophilic bacteria count of minced beef meat during storage.

The total number of Enterobacteriaceae is accepted as an indicator of hygiene in fish. Total Enterobacteriaceae count of the minced beef meat was found to be 1.59 log CFU/g at the beginning of the storage. At the end of the storage this value reached 4.77 log CFU/g in the control group while G0.5 and G1 reached 3.78 log CFU/g and 3.26 log CFU/g respectively. The effect of chitosan coating enriched with garlic essential oil emulsion on the total Enterobacteriaceae count in the minced beef meat is presented in figure 3.

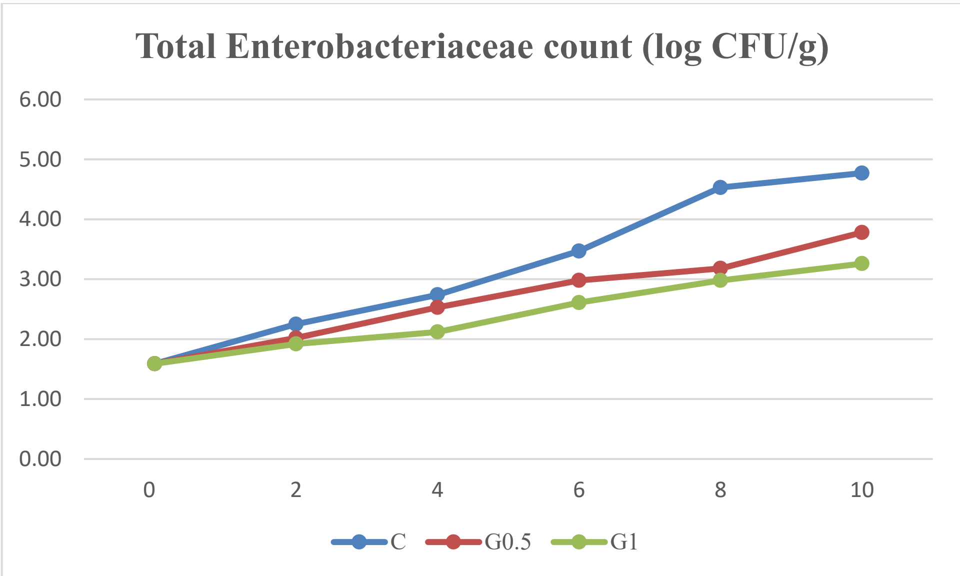


Figure 3. Changes in total Enterobacteriaceae count of minced beef meat during storage.

It was found that the G1 group with chitosan coating combined with 1% garlic essential oil showed strong antimicrobial effect. So, chitosan coating with garlic essential oil emulsion can be used to extend the shelf life of minced beef meat.

Antimicrobial properties of rosemary have been shown in studies using meatballs (Fernández-López et al., 2005), boiling beef (Ahn et al., 2007), lamb meat packed in a modified environment (Camo et al., 2008), and pig sausage (Pandit & Shelef, 1994). The compounds rosmarinic acid, rosmaridiphenol, carnosol, epirosmanol, carnosic acid, rosmanol, and isorosmanol work together to suppress the growth of microbes. These substances interact with the cell membrane, change nutrition, fatty acid synthesis, electron transport, genetic material, and cause cellular components to leak (Nieto et al., 2018).

Our findings are consistent with a different study that found that minced beef samples coated with a chitosan–kombucha tea coating exhibited a delay in microbial development throughout storage when compared to samples that were not coated (Ashrafi et al., 2018). Like the current findings, Hasani-Javanmardi et al. showed that a mixture of safflower oil and cumin essential oil reduced the amount of lactic acid bacteria, mesophilic and psychrophilic bacteria, and Enterobacteriaceae in samples of lamb meat (Hasani-Javanmardi et al., 2021). According to Langroodi et al. (2021), turkey breast flesh coated with chitosan and grape seed extract exhibited antibacterial activity against Enterobacteriaceae. According to other research, chitosan–cinnamon essential oil prevented the development of Enterobacteriaceae in beef patties both during storage and while refrigerated (Ghaderi-Ghahfarokhi et al., 2017). Georgantelis et al. (2007b) also found that samples containing chitosan and rosemary had the lowest microbial counts in pork sausages, suggesting a potential synergistic impact. Through MICs ranging from 0.01% to 1%, chitosan's antibacterial efficacy against several food spoilages and pathogenic microorganisms is well-established (Sagoo et al., 2002).

Conclusion

The study's results suggest that adding an emulsion of garlic essential oil to the chitosan coating can prevent microbiological development in beef meat for ten days while it is stored in the refrigerator. Therefore, to improve the microbiological quality of minced beef meat, garlic essential oil might be suggested as a natural antibacterial ingredient with chitosan coating.

Refrences

Abdou, E.S., Nagy, K. S. A., & Elsabee, M. Z. (2008). Extraction and characterization of chitin and chitosan from local sources. *Bioresource Technology, 99*(5), 1359–1367. https://doi.org/10.1016/ j.biortech.2007.01.051.

Ahmad, M., Benjakul, S., Sumpavapol, P., & Nirmal, N. P. (2012). Quality changes of sea bass slices wrapped with gelatin film incorporated with lemongrass essential oil. *International Journal of Food Microbiology*, *155*(3), 171-178.

Ahn, J., Grun, I. U., & Mustapha, A. (2007). Effects of Plant Extracts on Microbial Growth, Color Change, and Lipid Oxidation in Cooked Beef. *Food Microbiology*, *24*, 7–14.

Anonymous (1998). Bacteriological Analytical Manual, In (8th eds.). Association of Official Analytical Chemists, Gaithersburg ch.28.

Ashrafi, A., Jokar, M., & Mohammadi Nafchi, A. (2018). Preparation and Characterization of Biocomposite Film Based on Chitosan and Kombucha Tea as Active Food Packaging. *International Journal of Biological Macromolecules, 108,* 444–454.

Aydin, F., Kahve, H. I., & Ardic, M. (2017). Lipid-based edible films. *Journal of Scientific and Engineering Research, 4*(9), 86-92.

Beikzadeh, S., Khezerlou, A., Jafari, S.M., Pilevar, Z., & Mortazavian, A. M. (2020). Seed mucilages as the functional ingredients for biodegradable films and edible coatings in the food industry. *Advances in Colloid and Interface Science,* 102164. https://doi.org/10.1016/j.cis.2020.102164

Calo, J. R., Crandall, P. G., O'bryan, C. A., & Ricke, S.C. (2015). Essential oils as antimicrobials in food systems–a review. *Food Control, 54*, 111–119.

Camo, J., Beltrán, J. A., & Roncalés, P. (2008). Extension of the Display Life of Lamb with an Antioxidant Active Packaging. *Meat Science, 80,* 1086–1091.

Coma, V., Martial-Gros, A., Garreau, S., Copinet, A., Salin, F., & Deschamps, A. (2002). Edible antimicrobial films based on chitosan matrix. *Journal of Food Science, 67*(3), 1162-1169. https://doi.org/10.1111/j.13652621.2002.tb09470.x.

Da Silva, B. D., Bernardes, P. C., Pinheiro, P. F., Fantuzzi, E., & Roberto, C. D. (2021). Chemical composition, extraction sources and action mechanisms of essential oils: natural preservative and limitations of use in meat products. *Meat Science, 176,* 108463.

Devatkal, S. K., Thorat, P., & Manjunatha, M. (2014). Effect of vacuum packaging and pomegranate peel extract on quality aspects of ground goat meat and nuggets. *Journal of Food Science & Technology, 51*(10), 2685–2691. https://doi.org/10.1007/s13197-012-0753-5.

Duran, A., & Kahve, H. I. (2016). The use of chitosan as a coating material. *Academic Journal of Science*, *5*(1), 167-172.

Ebadi, Z., Khodanazary, A., Hosseini, S. M., & Zanguee, N. (2019). The shelf life extension of refrigerated *Nemipterus japonicus* fillets by chitosan coating incorporated with propolis extract. *International Journal of Biological Macromolecules*, *139*, 94-102.

Fernández-López, J., Zhi, N., Aleson-Carbonell, L., Pérez-Alvarez, J. A., & Kuri, V. (2005). Antioxidant and Antibacterial Activities of Natural Extracts: Application in Beef Meatballs. *Meat Science, 69,* 371–380.

Georgantelis, D., Blakes, G., Katikou, P., Ambrosiadis, I., & Fletouris, D. J. (2007b). Effect of rosemary extract, chitosan and a-tocopherol on lipid oxidation and colour stability during frozen storage of beef burgers. *Meat Science, 75,* 256–264.

Ghaderi-Ghahfarokhi, M., Barzegar, M., Sahari, M. A., Ahmadi Gavlighi, H., & Gardini, F. (2017). Chitosan-Cinnamon Essential Oil Nano-Formulation: Application as a Novel Additive for Controlled Release and Shelf Life Extension of Beef Patties. *International Journal of Biological Macromolecules*, *102,* 19–28.

Hasani-Javanmardi, M., Fallah, A. A., & Abbasvali, M. (2021). Effect of safflower oil nanoemulsion and cumin essential oil combined with oxygen absorber packaging on the quality and shelf-life of refrigerated lamb loins. *Lebensmittel-Wissenschaft & Technologie, 147,* 111557.

Helander, I. M., Nurmiaho-Lassila, E. L., Ahvenainen, R., Rhoades, J., & Roller, S. (2001). Chitosan disrupts the barrier properties of the outer membrane of gram-negative bacteria. *International Journal of Food Microbiology, 71,* 235–244.

Işık, H., Dağhan, Ş., & Gökmen, S. (2013). Gıda endüstrisinde kullanılan yenilebilir kaplamalar üzerine bir araştırma. *Gıda Teknolojileri Elektronik Dergisi*. *8*(1), 26-35.

Jackson-Davis, A., White, S., Kassama, L. S., Coleman, S., Shaw, A., Mendonca, A., Cooper, B., Thomas-Popo, E., Gordon, K., & London, L. (2023). A review of regulatory standards and advances in essential oils as antimicrobials in foods. *Journal of Food Protection, 86,* 100025.

Karimaei, S., Aghamir, S. M. K., & Pourmand, M. R. (2024). Comparative analysis of genes expression involved in type II toxin-antitoxin system in Staphylococcus aureus following persister cell formation. *Molecular Biology Reports, 51*(1), 324.

Karimaei, S., Mashhadi, R., Mirzaei, A., Deyhimfar, R., Shabestari, A. N., & Rahimnia, R. (2022). Antibacterial and antibiofilm activities of nisin from Lactococcus lactis and alteration of the bacteria-induced pro-inflammatory responses on kidney and bladder tumor cell lines. *Translational Research in Urology, 4,* 47–53.

Kuzgun, K. N., & İnanlı, G. A. (2013). Kitosan üretimi ve özellikleri ile kitosanın kullanım alanları. *Türk Bilimsel Derlemeler Dergisi, 6*(2), 16-21.

Latou, E., Mexis, S., Badeka, A., Kontakos, S., & Kontominas, M. (2014). Combined effect of chitosan and modified atmosphere packaging for shelf life extension of chicken breast fillets. *LWT–Food Science and Technology, 55,* 263–268.

Liu, H., Du, Y., Wang, X., & Sun, L. (2004). Chitosan kills bacteria through cell membrane damage. *International Journal of Food Microbiology, 95*(2), 147-155. https://doi.org/10.1016/j.ijfoodmicro.2004.01.022.

Lorenzo, J. M., Munekata, P. E., G´omez, B., Barba, F. J., Mora, L., Perez- Santaescol´astica, C., & Toldr´a, F. (2018). Bioactive peptides as natural antioxidants in food products–a review. *Trends in Food Science & Technology, 79,* 136–147.

Mehta, N., Ahlawat, S. S., Sharma, D. P., & Dabur, R. S. (2015). Novel trends in development of dietary fiber rich meat products-a critical review. *Journal of Food Science and Technology, 52*(2), 633–647, https://doi.org/10.1007/s13197-013-1010-2.

Mojaddar Langroodi, A., Nematollahi, A., & Sayadi, M. (2021). Chitosan Coating Incorporated with Grape Seed Extract and Origanum Vulgare Essential Oil: An Active Packaging for Turkey Meat Preservation. *Journal of Food Measurement and Characterization, 15,* 2790–2804.

Nieto, G., Ros, G., & Castillo, J. (2018). Antioxidant and Antimicrobial Properties of Rosemary (Rosmarinus officinalis, L.): A Review. *Medicines, 5,* 98.

Ojagh, S. M., Rezaei, M., Razavi, S. H., & Hosseini, S. M. H. (2010). Effect of chitosan coatings enriched with cinnamon oil on the quality of refrigerated rainbow trout. *Food Chemistry*, *120*(1), 193-198.

Olivera, D. F., Bambicha. R., Laporte, G., Cardenas, F.C., & Mestorino, N. (2013). Kinetics of colour and texture changes of beef during storage. *Journal of Food Science and Technology, 50*(4), 821–825. https://doi.org/10.1007/s13197-012-0885-7.

Pandit, V. A., & Shelef, L. A. (1994). Sensitivity of Listeria Monocytogenes to Rosemary (Rosmarinus officinalis L.). *Food Microbiology, 11,* 57–63.

Raji, F., Khanzadi, S., Hashemi, M., & Azizzadeh, M. (2019). Effect of chitosan coating nanoemulsion containing Zataria multiflora and Bunium persicum essential oils on Escherichia coli O157: H7 in vacuum-packed rainbow trout fillet. *Journal of Human Environment and Health Promotion, 5,* 21–25.

Rao, M. S., Chander, R., & Sharma, A. (2008). Synergistic effect of chitooligosaccharides and lysozyme for meat preservation. *LWT- Food Science and Technology, 41,* 1995–2001.

Renur, N. M., Haryadi, Y., Darmawati, E., & Kapelle, E. B. D. (2016). Application of chitosan and chinese lemon extract (*Citrus mitis*) based edible coating on tuna fillet. *International Journal of Food Sciences and Nutrition, 4*(2), 29-33.

Sagoo, S., Board, R., & Roller, S. (2002). Chitosan inhibits growth of spoilage microorganisms in chilled pork products. *Food Microbiology, 19,* 175-182.

Simona, J., Dani, D., Petr, S., Marcela, N., Jakub, T., & Bohuslava, T. (2021). Edible films from carrageenan/orange essential oil/trehalose structure, optical properties, and antimicrobial activity. *Polymers, 13,* 332.

Soltan Dallal, M. M., Siavashi, M., Karimaei, S., Siavashi, V., Abdi, M., Yaseri, M., Razavi, S.A., & Bakhtiari, R. (2024). The effect of thyme essential oil and endothelial progenitor stem cells on lipopolysaccharide-induced sepsis in C57BL/6 mice. *Biotechnology and Applied Biochemistry*, *71*(4), 835-848.

Ucak, I., & Afreen, M. (2022). Effect of Chitosan Coating Enriched with Peppermint Essential Oil Emulsion on the Microbiological Quality of Fish Meatballs. *Eurasian Journal of Food Science and Technology*, *6*(1), 60-68.

Ucak, I., Abuibaid, A. K. M., Aldawoud T. M. S., Galanakis C. M., & Montesano D. (2021). Antioxidant and antimicrobial effects of gelatin films incorporated with citrus seed extract on the shelf life of sea bass (*Dicentrarchus labrax*) fillets. *Journal of Food Processing and Preservation*, *45*(4), e15304.

Ucak, I., Yerlikaya, P., Khalily, R., & Abuibaid A. K. M. (2019). Effects of Gelatin Edible Films Containing Onion Peel Extract on the Quality of Rainbow Trout Fillets. Eurasian *Journal of Food Science and Technology*, *3*(2), 40-48.

Wi´nska, K., Mączka, W., Łyczko, J., Grabarczyk, M., Czubaszek, A., & Szumny, A. (2019). Essential oils as antimicrobial agents—myth or real alternative? *Molecules, 24*, 2130.

The Use of Rose Plants as an Early Warning Indicator for Powdery Mildew (*Erysiphe necator*) in Viticulture and the Evaluation of Image Processing-Based Applications

Tefide Kızıldeniz*, İremay Özalp

Department of Biosystems Engineering, Faculty of Agricultural Sciences and Technologies, Nigde Omer Halisdemir University, Niğde, Türkiye
ORCID Code: https://orcid.org/0000-0002-5627-1307 e-mail: tkizildeniz@ohu.edu.tr
Department of Biosystems Engineering, Faculty of Agricultural Sciences and Technologies, Nigde Omer Halisdemir University, Niğde, Türkiye
ORCID Code: https://orcid.org/0009-0003-1613-3967 e-mail: iremayozalp09@gmail.com

Abstract

Viticulture is of great agricultural and economic importance, with grapevine (*Vitis vinifera*) being one of the most widely cultivated fruits. Roses (*Rosa spp.)* are traditionally planted at vineyard edges as biological indicators due to their sensitivity to fungal pathogens like powdery mildew (*Erysiphe necator*), which causes major yield and quality losses in grapes. Early detection of this disease is essential.Artificial intelligence (AI), combined with imaging methods such as RGB, hyperspectral, and thermal imaging, provides fast and accurate disease diagnosis. AI models like SVM, KNN, ANN, and CNN have been used to analyze plant leaf features for disease classification. Since roses show powdery mildew symptoms earlier than grapevines, they can serve as early warning tools.This study aims to evaluate the potential of rose plants as early indicators of powdery mildew and assess the role of image processing techniques. This approach supports early, accurate disease management while reducing chemical use.Ultimately, the study promotes sustainable viticulture by offering affordable monitoring tools for farmers and paving the way for digital agriculture solutions in disease control.

Key Words: *Rose plant, grapevine, powdery mildew, image processing, artificial intelligence*

Introduction

The Importance of Diseases in Grapevine Cultivation

The share of diseases in grapevine cultivation is quite large. They directly affect yield and product quality. Since many harmful organisms, especially virus infections, cause weakening of plants and consequent yield and quality losses in vineyards, they are prioritized in quarantine and certification processes (Akbaş et al., 2021).

Effects of Powdery Mildew Disease on Grapevine

Grapevine mildew is an important disease caused by the oomycete Plasmopara viticola, which affects crops and landscapes exponentially due to its rapid spread under favorable conditions (Buonassisi et al., 2017). It causes serious damage and financial loss, including yield loss, reduced wine or product quality. The symptoms of powdery mildew disease on the vine are: Leaves are primary infection sites of downy mildew and serve as early disease indicators. Symptoms first appear at the stomata on the leaf underside, spreading to cover the whole leaf. Characteristic signs of the infection includes oil spots on the adaxial leaf surface and whitish downy on the abaxial surface (Gessler et al., 2011; Koledenkova et al., 2022).

The Traditional Role of the Rose Plant in Viticulture

Rose plants are planted on the edges of vineyards that are more susceptible to *Erysiphe necator*, the powdery mildew disease, due to their greater susceptibility to Sphaerotheca pannosa (Bonnie et al., 2016). Thus, their presence contributes to integrated pest management strategies, reducing the need for excessive chemical treatments and supporting sustainable viticulture.

Purpose and Scope of the Review

The aim of this review is to examine the role of rose (*Rosa spp*.) as a biological indicator for the early detection of powdery mildew disease, which is widely practiced in grapevine cultivation in Mediterranean countries. In particular, taking into account the process by which powdery mildew disease first shows symptoms on the rose and then infects the grapevine, it is aimed to determine the timing of infection progression between these two plants and to evaluate the potential of image processing techniques as an early detection tool in this process. In this context, the study examines the usability of the rose plant as a warning system against powdery mildew disease and aims to develop a perspective that can contribute to the improvement of disease management in grapevine by comparing the developmental stages of disease symptoms in rose and grapevine with image processing methods. It is also aimed to analyze the existing literature on the subject, identify research gaps and make recommendations for future studies.

Powdery Mildew

Causal Agent of Powdery Mildew Disease

The causal agent of powdery mildew in grapevine (*Vitis vinifera*) is the fungal pathogen *Erysiphe necator* (Gadoury, et al., 2012) that is obligately parasitic on genera within the Vitaceae, including Vitis, Cissus, Parthenocissus and Ampelopsis (Pearson and Gadoury, 1992). This pathogen is an obligate parasitic fungus that is widely prevalent in vineyards worldwide and can cause significant yield losses, particularly in warm and dry climates. The majority of commercially significant host is vine, especially the European grape varieties, V. vinifera, which is extremely sensitive to powdery mildew (Gadoury, et al., 2012).

This pathogen reduces the photosynthetic capacity of the grapevine, deteriorates cluster quality, and can lead to significant economic losses. Therefore, early warning systems, image processing, and remote sensing technologies are of great importance in this context.

Powdery Mildew Disease of Grapevine

Powdery mildew is an important fungal infection of all green parts of the grapevine plant, namely leaves, stems, shoots and panicles. The causal agent can infect the host at any developmental stage.

Both surfaces of the leaves are open to infection at any age, and mycelium, conidiophores and conidiospores developing on the surface appear as a gray-white, dusty or powdery layer. At the onset of the disease, chlorotic (light green-yellowish) bright areas resembling oil stains appear, especially on the upper surface of the leaves. Since these spots are mostly faint, they are difficult to recognize in the early stages.

Over time, infected leaves curl inward at the edges, thicken in texture and become brittle. Infected shoots are covered with blackish dark brown spots in the green stage and reddish brown spots in winter.

If the infection occurs during the fruiting period, the grape berries cannot complete their development; they remain small and deformed. This leads directly to yield and quality loss (Yildirim, 2020).

Powdery Mildew Symptoms on Rose Plants

Mildew first appears on the upper leaf surface as irregular, light green to reddish, slightly raised blister-like areas. The typical dense, powdery white growth of the mildew fungus (mycelium, conidiophores, and spores) soon becomes evident. Severely infected young leaves curl or bend irregularly and are often covered with the fungus's expanded, whitish-gray, powdery, fleshy or felt-like patches. These leaves usually turn reddish-purple under the mildew growth, then yellow, dry out, and fall prematurely. Older infected leaves usually remain intact but develop circular to irregular areas covered with flour-like mildew growth (Jafari et al., 2016).

Life Cycle and Infection Conditions of Powdery Mildew

Powdery mildew fungi generally exhibit both asexual and sexual life cycles. In the asexual cycle, the fungus spores (conidia) land on the surface of a susceptible plant and germinate to form a specialized structure called an appressorium. This structure penetrates the host plant's cell wall and forms a haustorium, which extracts nutrients from the plant cell. After a successful infection, the fungus branches and multiplies on the surface and produces spores again. This process causes disease symptoms in the form of white, powdery lesions on the plant.

In the sexual cycle, two compatible mycelia merge to form structures called chasmothecia. These structures contain sexual spores (ascospores) and usually form for overwintering purposes. In some species (such as *Erysiphe necator*), these structures are epidemiologically important because they can cause new infections in spring. However, in some species (such as Podosphaera xanthii), these structures are rarely seen or never form, so the sexual stage does not play a significant role in disease spread in these species (Vielba-Fernández et al.,2020).

Powdery mildew pathogens are widespread fungal organisms that can infect more than 10,000 plant species worldwide and are especially common in temperate and subtropical climate regions. The most important abiotic factors influencing their development and spread include temperature, humidity, light quality, air composition (particularly carbon dioxide and ozone levels), and air movement. Studies have shown that temperature and humidity are the most influential among these factors. However, environmental requirements vary between different powdery mildew species and can change depending on the stage of the pathogen's life cycle. In general, a temperature range between 13 and 30 °C provides optimal conditions for the development of powdery mildew; within this range, spore formation, dispersal, and infection capacity reach their highest levels (Mieslerová et al., 2022).

Partnership on Rose and Vine

Rose (*Rosa spp.)* and grapevine (*Vitis vinifera*) plants show similar symptoms and course of powdery mildew. In both plants, the disease manifests itself as a white, floury powdery coating on the leaves, shoots, and young branches. Powdery mildew fungi attach to the surface of the host plant, where they form mycelium and spores. As the infection progresses, their photosynthetic capacity decreases. In severe infections, shoots weaken, fruit development is negatively affected and yield decreases. The disease spreads rapidly under favorable climatic conditions (warm, low humidity weather).

Use of Rose Plant as a Biological Indicator

Reason for Planting The Rose by the Vineyard

Roses often serve as early indicators of upcoming infections in grapevines, such as black rot or downy mildew, since they tend to exhibit symptoms earlier (Pahl et al.,2021). His allows vineyard managers to take timely protective measures, such as fungicide applications, before the diseases spread to the grapevines—making roses a practical and visual tool in integrated vineyard disease management.

Timing of Infection Between Rose and Vine

Certain pathogens are capable of infecting their host plants through floral tissues during the blooming period. As observed in Erwinia amylovora, which infects apple and pear trees, the pathogen enters the plant via the flowers. A similar mechanism may be relevant for fungal or bacterial diseases affecting grapevines during their flowering stage (Thomson, 2000). Some pests may attack their host plants throughout the growing season, but they can cause significantly greater damage during specific phenological stages. For instance, larvae of the European grapevine moth (Lobesia botrana) are less harmful during the flowering period, whereas they can cause substantial economic losses during berry development (Gabel and Roehrich, 1995).

Powdery mildew disease symptoms begin as light-colored spots on the leaves during the early infection period and then spread rapidly with dense white mycelium and spore formation. The transition from the onset of infection to the active disease phase usually takes place within a few days (Jafari et al., 2016). The timing of infection of powdery mildew on roses and grapevines is similar; it usually starts on young leaves in spring and the disease cycle is completed in about 3 days.

The Importance of the First Symptoms in Rose Plants

All rose cultivars and varieties are susceptible to the disease, although they may differ greatly in their sensitivity (Debener and Byrne, 2014). Since rose plants show the first signs of fungal diseases such as powdery mildew before the grapevines, they are planted on the vineyard edges and used as an effective biological warning system for early detection and timely control.

Traditional Use of Rose in Vineyards

In the literature, studies on the control of powdery mildew disease mainly focus on traditional agricultural practices. In countries located within the Mediterranean climate zone, such as Spain and Italy, research shows that conventional methods such as cultural practices, chemical fungicide applications, and the use of resistant cultivars, are predominantly utilized. These regional practices often include avoiding dense planting, improving air circulation, and removing infected leaves to limit the spread of the disease. However, the number of such studies remains limited, and there is a noticeable lack of research incorporating modern technologies such as image processing, remote sensing, and AI-assisted monitoring systems. This gap highlights the need for innovative approaches in the early detection and monitoring of powdery mildew disease.

Disease Detection with Image Processing Methods

A Review of Image Processing Techniques for Plant Disease Detection

Image processing is an effective method used for fast and accurate detection of diseases and pests, which have become widespread in agriculture with the development of technology and especially reduce crop productivity. As an example, using the Image Processing Toolbox module of MATLAB software, the damage caused by the vineyard leaf scab (Eriophyes vitis) pest on vineyard leaves was detected (Altaş et al.,2021). Artificial Neural Networks (ANN) are an artificial intelligence method capable of recognizing disease symptoms from images of maize leaves. This approach analyzes features such as color, texture, and shape to accurately distinguish between healthy and diseased leaves (Bütüner et al., 2023). Classification of Plant Pests with Image Preprocessing Techniques and Deep Learning enables the automatic identification and classification of plant pests through image adjustment processes and deep learning algorithms (Eze et al., 2024).

Image Processing Algorithms

RGB imaging is an image acquisition method that uses red, green and blue color components and is widely used in various agricultural applications (Travlos et al., 2017). Thanks to its advanced structure, RGB imaging technology has enabled detailed and cost-effective monitoring of crop health, weed detection and field variability. In this respect, it has gained an important place in agricultural decision support systems (Jiang vd. 2019).

Hyperspectral imaging is a more advanced technology compared to RGB imaging and has attracted considerable interest in agricultural applications and food processing in recent years. Sensors with this technology can detect not only the visible light range, but also a much wider part of the electromagnetic spectrum, especially infrared wavelengths. This provides detailed and comprehensive data on the chemical and physical properties of products, enabling high-precision analysis in areas such as quality control, disease detection and product monitoring (Çetin et al., 2022).

Thermal imaging is a technology that visualizes temperature distribution by detecting infrared radiation emitted by objects. This method is widely used in agriculture, especially in areas such as early detection of plant stress (lack of water, disease, etc.) (Hu et al., 2011). In addition to detecting plant stress, this technology makes it possible to monitor irrigation needs and identify pest or disease infested areas. It is thus used as an effective decision support tool to increase productivity and optimize resource use in agricultural production (Vadivambal and Jayas, 2010).

Visual Symptoms of Powdery Mildew

In powdery mildew infections, morphological signs (the pathogen visible to the naked eye) typically appear before morphological symptoms. This is partly due to the fact that powdery mildews are obligate parasites that harm their hosts slowly, and partly because their mycelium and conidiophores are large, white, and superficial, making them easy to detect. Additionally, since powdery mildews are rarely systemic, significant damage only occurs when a plant is infected by numerous independent infections (Yarwood et al., 1957).

Algorithms for Disease Detection in Rose and Grapevine Leaves

Neural Networks for Rose Cultivation

This approach enables the segmentation of images into leaf and background regions. A variety of size and color features are extracted from both the RGB and HSI representations of the images. These parameters are then fed into neural networks and mathematical classifiers, which are used to determine the plant's health condition (Sawarkar et al., 2018).

Support Vector Machine (SVM) for Rose Cultivation

During implementation, multiple color representations are used. The segmentation between leaf and background is handled by an MLP (Multilayer Perceptron) neural network, which uses a color library created beforehand using an unsupervised Self-Organizing Map (SOM). The colors on the leaf surfaces are clustered using another unsupervised SOM, and a genetic algorithm determines the number of clusters to be used. Finally, an SVM classifier separates diseased and healthy regions (Sawarkar et al., 2018).

Fuzzy Classifier for Rose Cultivation

This method aims to detect four different nutritional deficiencies in plants. Although the segmentation is based on color similarity, detailed steps are not provided by the authors. Once the segmented regions are identified, texture and color features are extracted and processed using a fuzzy classifier. The system then determines the type and degree of deficiencies and suggests the required fertilizer amount for correction (Sawarkar et al., 2018).

Color Analysis for Rose Cultivation

The method was tested on various plants. Before analysis, images are converted into HSI and Lab color spaces. The color differences between healthy and unhealthy leaves are calculated using geometric distances, allowing the identification of possible deficiencies (Sawarkar et al., 2018).

Feature-Based Rules for Rose Cultivation

This approach identifies and labels three types of plant diseases. Healthy leaf regions and diseased parts are segmented, and thresholding methods are applied. The authors tested local entropy and Otsu's method, concluding that Otsu's method yields more accurate results. Subsequently, color and shape features are extracted and used to build rule-based classifiers that best match the identified disease symptoms.K-Nearest Neighbor (KNN) is a simple yet effective machine learning classification algorithm. It determines the class of a given query sample by identifying its k-nearest neighbors in the feature space. The classification is based on measuring the minimum distance between the query point and the training data points.In the context of plant leaf classification, the algorithm calculates the distance between the test samples and the training samples. Then, based on the most common class among the nearest neighbors, it assigns a class label to the query sample. This method is particularly useful due to its simplicity and effectiveness in handling non-linear data (Sawarkar et al., 2018). Disease detection and pesticide management using CNN refers to detecting diseases on rose leaves and managing pesticide application through the use of Convolutional Neural Networks (CNN) (Khaleel et al., 2022).

Rose plant disease detection with deep learning" refers to identifying diseases in rose plants using deep learning techniques (Ali-Al-Alvy et al., 2023). A rose plant disease detection based on a combination of infrared and visible images" refers to detecting diseases in rose plants using a combination of infrared and visible light images (Minaei et al.,2018).

Algorithms for Disease Detection in Grapevine Leaves

An automated system using image processing and machine learning techniques has been developed for the detection of grapevine diseases. The system separates the leaf (region of interest) from the background using k-means segmentation. From the resulting leaf region, diseased areas are further segmented using global thresholding and semi-supervised methods (Jaisakthi et al., 2019).

The Adaptive Snake algorithm model is used for grape leaf segmentation, providing high accuracy in disease identification. This method enables precise separation of diseased areas by precisely identifying leaf contours (Shantkumari et al., 2021).

Artificial Intelligence-Based Classification Approaches

Unlike traditional machine learning and image processing techniques, deep learning performs the learning process directly on the raw data. As it processes the raw data, it extracts the necessary information through the representations it creates in different layers. Deep learning first gained widespread attention with its success in ImageNet, a large-scale visual recognition competition held in 2012 (İnik et al., 2017). Thanks to models trained with the effective use of computer vision and deep learning methods, we can accurately diagnose the plant's disease in each of our predictions (Esen et al., 2022).

AI-based classification methods utilize machine learning and deep learning techniques to identify patterns in data and classify objects into specific categories. These methods are becoming increasingly popular due to their high accuracy and flexibility, especially for complex and large data sets. Commonly used AI-based classification techniques in literature include Support Vector Machines (SVM), K-Nearest Neighbor (KNN), Decision Trees, Random Forests, Artificial Neural Networks (ANN) and Deep Neural Networks (DNN and CNN). In addition, fuzzy logic-based classifiers have also attracted attention as effective methods for analyzing data structures containing uncertainty and fuzziness. These approaches provide flexibility and superior performance in solving classification problems in different application areas.

Future Perspectives and Research Gaps

Gaps in Current Research

Most of the existing studies in the literature base the use of rose plants as disease indicators on visual observations only, and comprehensive analyses supported by the temporal course of infection, symptom development times and digital measurement techniques are not sufficiently included. In particular, the simultaneous application of image processing methods on rose and grapevine plants has been very limited, and statements that the disease appears in the rose plant before the vine are mostly based on qualitative observations. Furthermore, although it is known that there may be variability in the time of onset of disease symptoms between different species (cultivars) of roses, these biological variations have been largely ignored in the literature.

Validity and Adaptation in Different Climates

Although it is well documented in the literature that the rose-vine relationship is widely used in the Mediterranean climate zone, especially in Italy and Spain, there is a lack of scientific studies on whether this model is similarly effective in continental, humid or tropical climates. Abiotic environmental factors such as temperature, humidity and UV radiation in different geographical regions can directly affect the rate of infection development of powdery mildew, which can significantly alter the functionality of rose as an indicator plant. Therefore, there is an urgent need for climate-based validation studies testing the validity of rose as an indicator plant in different climates.

Multidisciplinary Research Proposals

The integrated use of plant pathology, image processing and artificial intelligence disciplines enables the temporal tracking of disease transmission between roses and grapevines, which in turn enables the development of early warning prediction algorithms. Likewise, by combining plant physiology, microbiology and remote sensing, it may be possible to monitor temperature changes and detect the onset of infection at the microscopic level before visible symptoms appear on the leaf surface. Furthermore, phenological modeling of the rose-vine system can be used to predict the times of the year when the risk of disease is higher, thereby increasing the effectiveness of warning systems.

Alternative Indicator Plants Other Than Roses

Although rose has been used as an effective early warning plant in viticulture, the potential of native plant species as indicators in regions with different climatic and environmental conditions has not been sufficiently evaluated in the literature. In particular, testing species that tend to react early to fungal pathogens, such as Calendula (marigold), Zinnia, legumes or some wild plant species, as indicator plants could open up new and unique areas of research. Such alternative indicators may offer more flexible and locally-oriented solutions that can be applied in areas where the rose plant has limited adaptation to soil structure, climatic zone or biotic stress conditions.

The Rose's Potential as an Indicator

Rose plant is considered as a biological indicator with high potential for early detection of fungal infections in viticulture, especially powdery mildew disease. Many practices in the literature show that planting roses at the edge of the vineyard gives symptoms of the disease before it spreads to the vine and thus contributes to timely precautions.

Contribution of Image Processing Methods

This function stands out as both a visual and practical tool in integrated disease management strategies.

With the development of image processing methods, it is now possible to detect disease symptoms not only by eye but also by digital image analysis. With techniques such as RGB, thermal and hyperspectral imaging, early symptoms on rose petals can be detected quickly, accurately and free from human error.

Integrated System Proposal and the Importance of Early Intervention

Through the use of algorithms such as deep learning, artificial neural networks and SVM, these data can be classified and transformed into systematic decision support systems.

In this direction, the proposed integrated system model includes analyzing image data from rose plants with machine learning algorithms, generating instant disease alerts and automatically determining the intervention time on the vine. Such a system can both increase agricultural productivity and support sustainable viticulture by reducing the need for chemical control. Early detection should be considered as one of the key components of integrated farming practices, as it allows the disease to be controlled before it spreads.

Implementation Scenarios for Farmers

Planting rose plants as an early warning system at the vineyard edge is a cost-effective and feasible method of disease monitoring for farmers. Symptoms of fungal diseases such as powdery mildew on rose leaves can appear days or weeks before infection on the vine, giving the farmer time for early intervention. Supported by image processing techniques, the farmer can analyze the image of rose leaves through a mobile app or camera-assisted system. When the app detects signs of disease, it can send an automatic notification to the farmer to initiate spraying or cultural measures. This model offers an effective disease management tool without requiring large investments, especially for small and medium-sized vineyard enterprises. It also encourages targeted chemical intervention only when necessary, in line with the principles of sustainable agriculture.

References

Akbaş, B., Morca, A. F., and Coşkan, S. (2021). Türkiye'de Belirlenen Bağ Virüs Hastalıklarının Tarihsel Gelişimi ve Önemi. Bahçe, 50(2), 155-165.

Hernández, I., Gutiérrez, S., & Tardaguila, J. (2024). Image analysis with deep learning for early detection of downy mildew in grapevine. Scientia Horticulturae, 331, 113155.

Ownley, B. H., & Trigiano, R. N. (2016). Plant pathology concepts and laboratory exercises. CRC press.

Yildirim, İ.(2020). Bağ küllemesi (uncinula necator (schw.) burr.)ne karşı alternatif savaşım yöntemleri üzerinde araştırmalar.

Jafari, M., Minaei, S., Safaie, N., & Torkamani-Azar, F. (2016). Early detection and classification of powdery mildew-infected rose leaves using ANFIS based on extracted features of thermal images. Infrared Physics & Technology, 76, 338-345.

Mieslerová, B., Aşçı, R. T., Wheater, C. P. ve Lebeda, A. (2022). Külleme ekolojisi - abiyotik faktörlerin gelişimi ve epidemiyolojisi üzerindeki etkisi. Bitki Bilimlerinde Eleştirel İncelemeler, 41(6), 365-390.

Vielba-Fernández, A., Polonio, Á., Ruiz-Jiménez, L., de Vicente, A., Pérez-García, A., & Fernández-Ortuño, D. (2020). Fungicide resistance in powdery mildew fungi. Microorganisms, 8(9), 1431.

Gadoury, D. M., Cadle-Davidson, L. A. N. C. E., Wilcox, W. F., Dry, I. B., Seem, R. C., & Milgroom, M. G. (2012). Grapevine powdery mildew (Erysiphe necator): a fascinating system for the study of the biology, ecology and epidemiology of an obligate biotroph. Molecular plant pathology, 13(1), 1-16.

Pearson, R.C. and Gadoury, D.M. (1992) Grape powdery mildew. In: Plant Diseases ofInternational Importance, Vol. III. Diseases of Fruit Crops (Kumar, J., Chaube, H.S.,Singh, U.S. and Mukhopadhyay, A.N., eds), pp. 129–146. Englewood Cliffs, NJ: Pren-tice Hall

Pahl, H. L. (2021). Sentinel mutasyonları: bağdaki güller. Kan, Amerikan Hematoloji Derneği Dergisi, 138(21), 2019-2020.

Jafari, M., Minaei, S., Safaie, N., & Torkamani-Azar, F. (2016). Early detection and classification of powdery mildew-infected rose leaves using ANFIS based on extracted features of thermal images. Infrared Physics & Technology, 76, 338-345.

Salgado-Salazar, C., Shiskoff, N., Daughtrey, M., Palmer, C. L., & Crouch, J. A. (2018). Downy mildew: A serious disease threat to rose health worldwide. Plant disease, 102(10), 1873-1882.

Altaş, Z., Özgüven, M. M., & Dilmaç, M. (2021). Görüntü işleme teknikleri ile bağ yaprak uyuzu hasarının belirlenmesi. Gaziosmanpaşa Bilimsel Araştırma Dergisi, 10(3), 77-87.

Bütüner, R., Şimşek, M., Aksöz, G., & Şan, S. (2023). Yapay Sinir Ağları ile Mısır Yapraklarında Hastalık Tespiti. Journal of Information Systems and Management Research, 5(2), 21-31.

Eze, Ş. E., & Berkaya, S. K. (2024). Görüntü Ön Işleme Teknikleri Ve Derin Öğrenme Ile Bitki Zararlilarinin Siniflandirilmasi. Mühendislik Bilimleri ve Tasarım Dergisi, 12(2), 455-465.

Özgüven, M. M., Türker, U., Çetin, N., & Çolak, A. (2025). Tarımda Dijital Çağın Getirdiği Yenilikler İklim Akıllı Tarım Ve Sürdürülebilir Uygulamalar. Türkiye Ziraat Mühendisliği X. Teknik Kongresi Bildiriler Kitabı-1, 246.

Yarwood, C. E. (1957). Powdery mildews. The Botanical Review, 23(4), 235-301.

Sawarkar, V. ve Kawathekar, S. (2018). Bir inceleme: Görüntü işleme kullanarak gül bitkisi hastalık tespiti. IOSR Bilgisayar Mühendisliği Dergisi (IOSR-JCE) e-ISSN, 2278-0661.

Khaleel, M. I., Sai, P. G., Kumar, A. U. R., Raja, P. ve Hoang, V. T. (2022, Nisan). Gül bitkisi yaprakları: Cnn kullanarak hastalık tespiti ve pestisit yönetimi. 2022 yılında 6. Uluslararası elektronik ve bilişim trendleri konferansı (ICOEI) (s. 1067-1072). IEEE.

Ali-Al-Alvy, M., Khan, G. K., Alam, M. J., Islam, S., Rahman, M., & Rahman, M. S. (2023, Nisan). Derin öğrenme kullanarak gül bitkisi hastalık tespiti. 2023'te 7. Uluslararası Elektronik ve Bilişim Trendleri Konferansı (ICOEI) (s. 1244-1249). IEEE.

Minaei, S., Jafari, M. ve Safaie, N. (2018). Kızılötesi ve görünür görüntülerin bir kombinasyonuna dayalı bir gül bitkisi hastalık tespiti ve sahaya özgü ilaçlama sisteminin tasarımı ve geliştirilmesi. Tarım Bilimi ve Teknolojisi Dergisi, 20(1), 23-36.

Jaisakthi, S. M., Mirunalini, P., & Thenmozhi, D. (2019, February). Grape leaf disease identification using machine learning techniques. In 2019 International conference on computational intelligence in data science (ICCIDS) (pp. 1-6). IEEE.

Shantkumari, M., & Uma, S. V. (2021). Grape leaf segmentation for disease identification through adaptive Snake algorithm model. Multimedia tools and applications, 80(6), 8861-8879.

İnik, Ö., & Ülker, E. (2017). Derin öğrenme ve görüntü analizinde kullanılan derin öğrenme modelleri. Gaziosmanpaşa Bilimsel Araştırma Dergisi, 6(3), 85-104.

Esen, F. A., & Onan, A. (2022). Derin Öğrenme Yöntemleri ile Bitki Yaprakları Üzerindeki Hastalıkların Sınıflandırılması. Avrupa Bilim ve Teknoloji Dergisi, (40), 151-155.

Modeling the Process Of Interaction Of Loosening Organs With Soil

Feruza Alimova[1], Mukhayyokhon Saidova [1]

Feruza Alimova[1], Mukhayyokhon Saidova [2]
m.saidova87@mail.ru , feruza.alimova.1961@mail.ru

Abstract

The article presents data on the simulation modeling of the technological process of soil loosening, which helps to increase the accuracy of assessing the efficiency of soil-cultivating units, analyzing the energy intensity of the process and choosing optimal loosening modes. The aim of the study is to determine the distribution of stresses, deformations and soil resistances on the working bodies of a two-tier ripper. Key models for determining soil porosity, plasticity, resistance to deformation and hardness are considered. Using the COMSOL Multiphysics application software package, a simulation model of the soil in the process of its interaction with the working parts of the tool was created. A calculation scheme for the problem of soil loosening with a two-tier ripper is presented using the COMSOL application software package. According to the results of the study, the highest values of the projection of the main stress are observed in the direction Oy, and in other directions they are negligibly small; on the ridges of the two-tier ripper they are the same and distributed evenly. The results of the study of the stress-strain state of the working bodies and soil during loosening were obtained, critical zones in the design of the working bodies were determined, which will increase their wear resistance and durability with further optimization of the parameters of the tillage tool.

Key Words: *soil-cultivating, working bodies, energy, modeling.*

Introduction

Improvement of design and operational parameters of machine and tractor aggregates must be carried out through joint research of systems operating in conjunction with each other, while taking into account their dynamic operating modes, environmental conditions, and technical and operational parameters of the aggregates. A detailed analysis of the technological process of soil cultivation, determination of agrotechnical and energy indicators of a soil-cultivating tool is possible when developing a model of the process of interaction of its working parts with the soil.

The main parameters that must be taken into account for an adequate representation of the soil cultivation process model are the design of the soil cultivation tool and the physical and mechanical properties of the soil

It is known that when working bodies act on the soil, elastic and plastic deformations occur simultaneously in it, both in the cut layer and in the displaced soil particles. These processes are closely interconnected and form a single system of soil cultivation.

Various authors have used systems analysis to analyze various processes [1; 2; 3]. Successful implementation of these processes requires the development of new technologies and new working bodies. The physical and mechanical properties of the soil have a significant impact on the agrotechnical indicators and traction resistance of soil-cultivating machines.

Soil as a technological environment is characterized by parameters that change in time and space; the physical and mechanical properties of the soil change depending on weather conditions, crop rotation, application of fertilizers to the soil, etc. Analysis of the research shows that the study of soil deformation under the impact of tillage tools is possible by analyzing the nature of soil deformation under the impact of a wedge. A deep analysis of the relationships between the design of tillage working bodies and the efficiency of the tillage process is given in the works [4, 5, 6]. According to classical agricultural mechanics, the main part of the working bodies of soil-cultivating implements is considered as a type of dihedral or trihedral wedge [7, 8].

In the works of researchers [9, 10], the connections between the geometric parameters of the modeled surface and the agrotechnical and technological parameters of the working element were determined based on the analytical method of constructing the surface by L.V. Gyachev. Applying the theory of soil deformation, scientists considered

the stresses in the soil layer under the action of a group of forces along the profile of the working element as discrete quantities, i.e. as the sum of the stresses from the action of individual forces. Models of soil destruction are constructed taking into account the structure of the soil environment, the variability of mass, its deformation and destruction.
The rheological model of a Newtonian viscous fluid was also used as a soil model, which made it possible to simulate the processes of deformation and movement of the soil, as well as to study the phenomena occurring within the massif [11]. Such studies were conducted using the FiowVision software package. Currently, when developing a mathematical model of the soil cultivation process, scientists use the discrete element method [12, 13]. It has been established that the Hertz-Mindlin contact models taking into account adhesion and cohesion are suitable models for describing the type of connections between soil particles.
For modeling using the discrete element method, the main physical and mechanical properties of soil particles were established, namely Poisson's ratio, coefficient of static friction, shear modulus, Young's modulus, and particle density. The developed mathematical models allowed us to represent the process of mechanical tillage, determine the traction resistance of a tillage machine under various parameters, study the stress-strain state of its working parts and soil, and the nature and direction of soil movement during tillage.
Soil properties are divided into physical: soil density (ρ), which is classified as density in the natural state (ρ_n), true density of soil particles ((ρ_s) and dry soil ((ρ_d); humidity (W), porosity (n), specific gravity of soil (γ);
and mechanical: compressive strength - expresses the ability of the soil to resist destruction under load; shear strength (angle of internal friction and adhesion), the angle of internal friction (φ) and cohesion (c) determine the resistance of the soil to shear; the deformation modulus (E) describes the ability of the soil to elastic deformation under load; the compressibility coefficient (m) characterizes the change in the volume of the soil under pressure [14].

Materials and Methods

The process of developing new working bodies, as well as optimizing design and technological parameters, is based on mathematical models and the obtained regularities. The process of soil cultivation is always unstable due to changes in the actual depth of cultivation and the physical and mechanical properties of the soil, wear of the working element and its individual elements, and other factors. Identifying the nature of the interrelations of factors that contribute to increasing the efficiency of soil-cultivating aggregates, and developing working bodies to ensure optimal results at all stages of the soil cultivation process under changing soil conditions are urgent scientific tasks.
The management of the soil cultivation process consists of obtaining the necessary indicators based on the knowledge of the parameters of the working element, the cultivation method, the method of cutting and loosening, the properties of the technological environment, by regulating the operating mode of the system. They must comply with agrotechnical, environmental, operational and safety requirements.
The following are accepted as input parameters of the loosening process as a system: soil properties, design of the tillage tool and working bodies, method of fastening the working bodies to the frame and to each other; location of the cultivated area on the slope.
The main output parameters are the parameters of the stress-strain state of the soil and the structure of the unit, the distribution of longitudinal and vertical stresses, and critical zones in the design of the working bodies.

Results and Discussion

In mechanical tillage in agriculture, various mechanical models are used that describe the interaction of the soil with the working parts of agricultural machinery. These models help to predict soil resistance, tool forces, energy intensity of processing and the quality of the work performed. In soil science, soil mechanics and agrophysics, there are a number of mathematical models for determining the porosity, plasticity, resistance to deformation and hardness of the soil: calculation of soil properties using the Mohr-Coulomb criterion (the relationship between soil porosity and density); Proctor's model for soil hardness (relationship between compaction and soil moisture); V.P.Goryachkin's classical model of general soil resistance based on the balance of forces and soil deformation [15, 16].
Let's look at the key models for each of these properties.
Relationship between soil porosity and density

$$P=1-\frac{\rho_b}{\rho_s},$$

where: ρ_b - soil density (volumetric), ρ_s - soil solid density

ρ_s = 2,65…2,75 g/cm3.
Proctor's model for soil hardness. The relationship between compaction and soil moisture is quadratic:

$\rho_b = A + BW - CW2$,

where: A,B,C - coefficients determined experimentally.
Soil failure model (Mohr-Coulomb) - soil is considered a plastic material that fails by shear:
$\tau = c + tg\varphi$,
where: τ - shear stress, c - cohesion, φ - angle of internal friction.
Determines the limiting state of the soil when interacting with the tool. Used to calculate the forces of interaction between the ploughshare and the soil. Resistances to cutting, friction and shear are taken into account.
Dependence of forces on the angle of attack and speed
:
$R=\sigma \cdot A+\tau \cdot l \cdot R$,
where: R - resistance, σ - normal voltage, A - contact area, τ - shear stress, l - contact length.
For a given soil the following parameters are known: specific cohesion c = 25 kPa; angle of internal friction φ = 30^0; normal stress σ = 50 kPa.
It is necessary to calculate the shear stress τ, at which the shift will occur, and check the stability of the soil under a given load. Substituting the known parameters, we obtain: τ = 53.85 kPa; soil density ρ_b = 1.3g/cm3; b = 1,3 g/cm3.
Clay content: C=40%; Specific adhesion: c=30 kPa; Friction angle: φ = 25^0; Humidity: W = 15%; a = 10; b = 0,5; k = 0,1.
Optimal humidity. For pre-sowing treatment:

$$W_{onm} = \frac{a+b\cdot C}{1+k\cdot\rho_b} = \frac{10+0.5\cdot 40}{1+0.1\cdot 1.3} = 18\%$$

Specific resistance to loosening

$$F = k{\rho_b}^n W^m = 100\cdot 1{,}3^{1.5}\cdot 0{,}15^{\,0{,}8} \approx 204 \text{ kPa}$$

According to the calculation results: the optimum humidity for processing is 18%.; the soil is stable at shear stresses of up to 53.3 kPa; the recommended traction force for equipment is calculated based on a specific resistance of 204 kPa.

Simulation model of soil loosening

Simulation of a two-tier ripper in Comsol Multiphysics allowed us to obtain detailed data on the complex relationships between the mechanical properties of materials and external loads. Such modeling can be useful for optimizing the geometry of the working bodies of a two-tier ripper in engineering applications. However, when modeling, it is important to select a model of the process of interaction of the working parts of a two-tier ripper with the soil that most adequately describes the technological process and meets agrotechnical requirements. These results highlight the importance of detailed numerical analysis, which not only reveals key features of stress and strain distribution, but also suggests ways to optimize the design to improve its reliability and durability.
According to the design, the working parts (loosening paws) are used for non-moldboard surface tillage of the soil, i.e. loosening it to a depth of 16….30 cm and a width of 55….250 mm.
When calculating the work of a two-tier ripper, it is important to take into account the soil resistance and the reaction that occurs when the working element interacts with the soil. This includes calculations for the bending and strength of the working element, an assessment of the resistance force and the energy expended on loosening.
To model a two-tier ripper, it will be necessary to develop a system of equations that describes the physical processes associated with the contact interaction of the soil and the working elements.

Statement of the problem

The equations of motion of the stress state of mechanisms for loosening the soil in a three-dimensional statement in the Cartesian coordinate system $Ox1x2x3$, under the action of a system of surface and volumetric forces have the form [17].

$$\sigma_{ij} + X_i - \rho\ddot{U}_i = 0,$$

defining relations between the stress tensor σ_{ij} and deformations ε_{ij}

$$\sigma_{ij} = C_{ijkl}\,\varepsilon_{kl}$$

U_i and geometric Cauchy relations between ε_{ij} and the components of the displacement vector - U_i

$$\varepsilon_{ij} = \frac{1}{2}(U_{i,j} + U_{j,i} + U_{k,i}\,U_{k,j})$$

and boundary conditions

$$U_i\big|_{\Sigma} = U_i^{\Sigma}, \quad \sigma_{ij}n_j\big|_{\Sigma} = S_i$$

Where: X_i, S_i are volume and surface forces, U_i^{Σ} are specified on a part of the displacement boundary, n_j is the external normal, ρ is the density, C_{ijkl} (x)- are the elastic moduli, $i, j, k, l = 1, 2, 3$. For isotropic materials, the following relationships hold for the components of the elastic moduli tensor

$$C_{ijkl} = \lambda\,\delta_{ij}\delta_{kl} + \mu\,(\delta_{ik}\delta_{jl} + \delta_{il}\delta_{jk}),$$

where: $\lambda = \frac{E\nu}{(1-2\nu)(1+\nu)}$; $\mu = \frac{E}{2(1+\nu)}$ Lame coefficients, E is the elastic modulus, ν is Poisson's ratio.

In this problem, the volume forces - X_i are absent. The total soil resistance force for the stand with a tip is used as the surface force S_i, which is specified for a two-tier ripper and can be calculated using the following formula:

$S_1 = F_t$; $S_2 = F_w$; $S_3 = F_n$

Calculation scheme for the problem of soil loosening with a two-tier ripper on the Comsol application software package.

Soil contact interaction: modeled using contact conditions where soil resistance forces act on the posts and tips. Boundary conditions may include normal and tangential forces depending on the soil type and the angle of attack of the post. Resistance coefficients such as the angle of internal friction and cohesion can be used to model contact pressure. Figures 1 and 2 show the layout of the finite elements of the problem under consideration for loosening the soil with a two-tier ripper and its design. In the areas of impact of the tip on the soil, the number of finite elements increases, while the area of the element itself decreases. As a result, the degree of adequacy of mathematical modeling increases significantly.

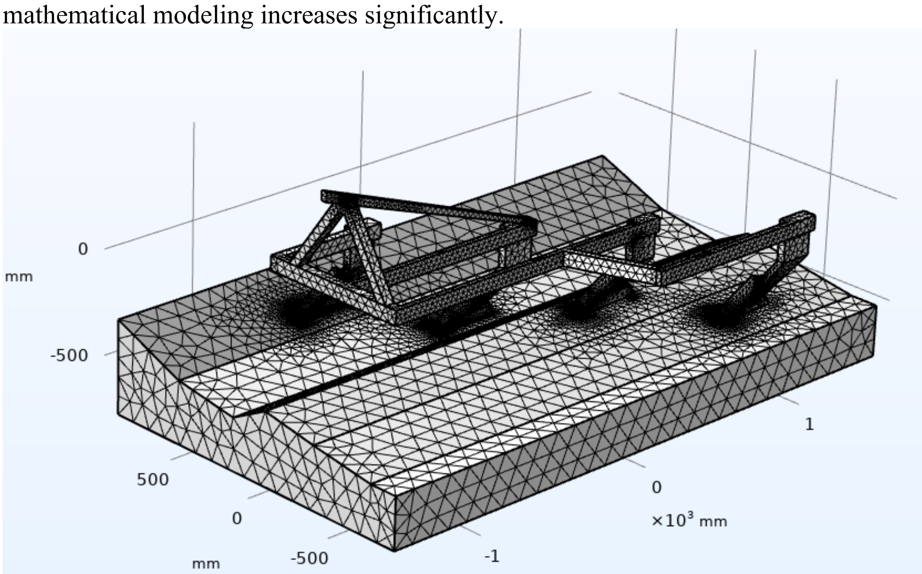


Fig. 1 Scheme of discretization of the composition "two-tier ripper-soil"

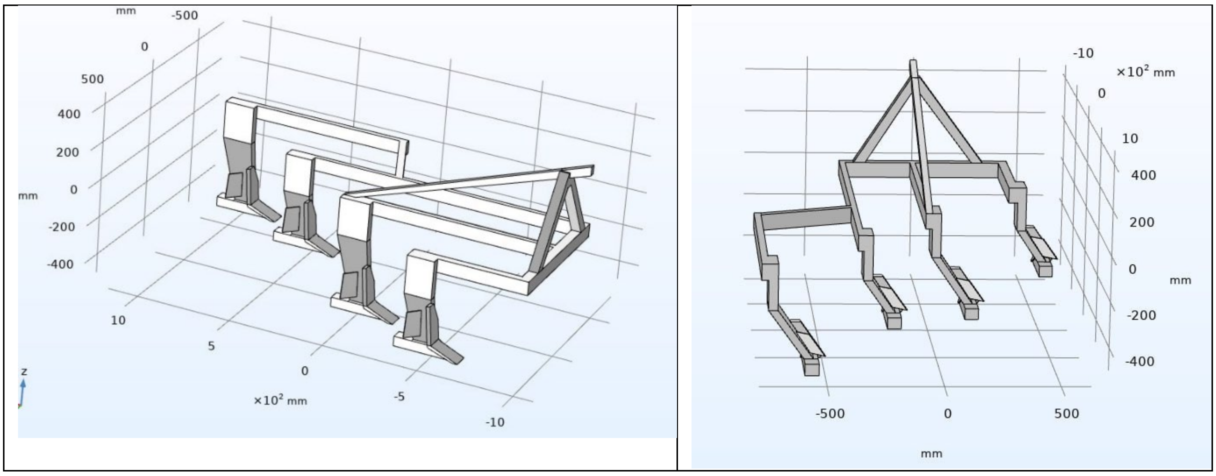
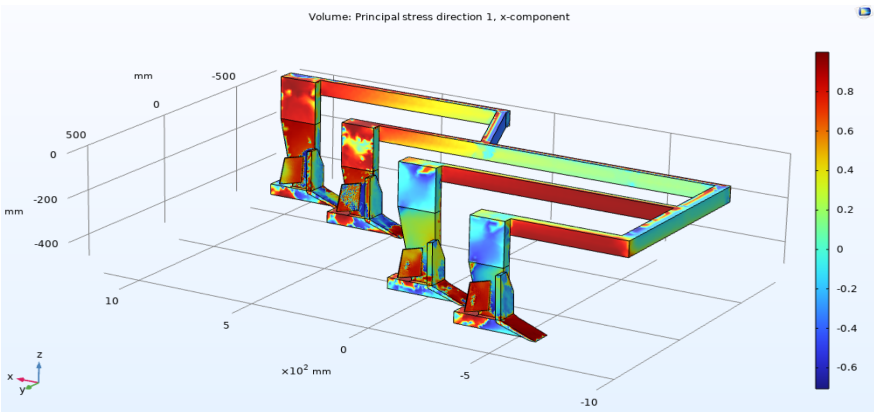


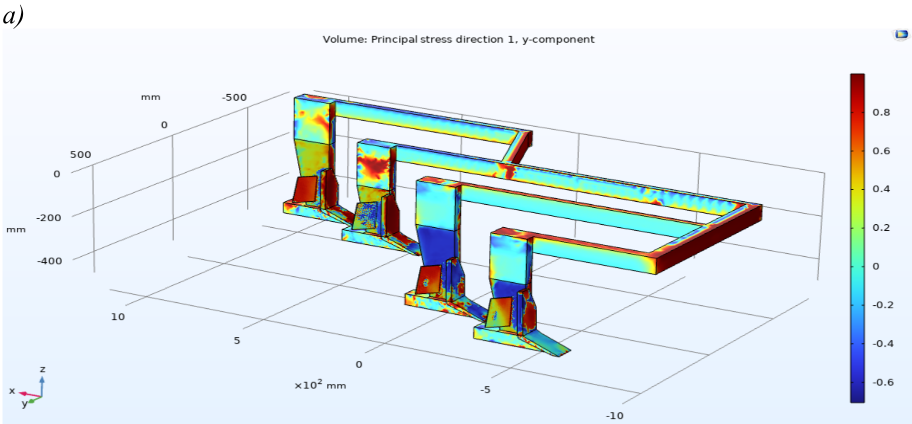
Fig. 2. Construction of a two-tier ripper

As the obtained results show, the highest values of the projection of the main stress $\vec{\sigma}_1$ in the direction *Ox* are observed on the *4*th post and *1,2,4* beams of the two-tier ripper (Fig. 3,*a*.). This fact can be explained by the fact that, according to the design feature, the tip *4* of the *4* th working element cuts deeper into the soil, as a result of which the highest stress concentration is achieved for $\vec{\sigma}_1$..

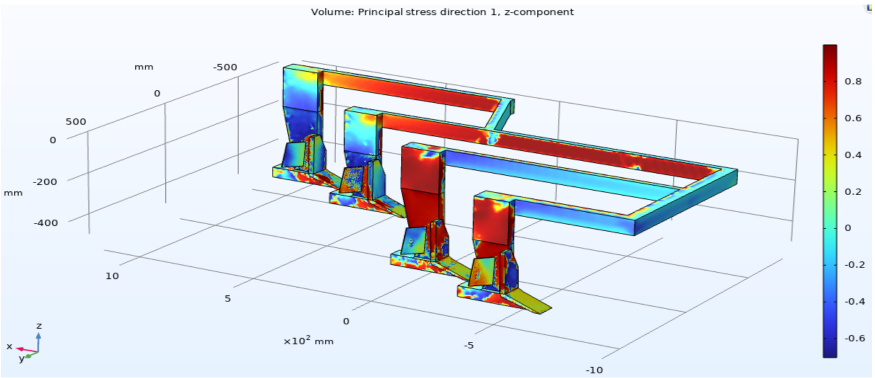
As expected, the concentration of the main stress -$\vec{\sigma}_1$. is not observed in the direction *Oy*, since the movement of the unit occurs in the *Oxz* plane (Fig. 3,*b*.). Due to the technological feature, the main share of the main stress $-\sigma_x$ is distributed to the first and second posts of the two-tier ripper. At the same time, the main share of the vertical pressure, without being transmitted to the *3*rd and *4*th post, is retained on the corresponding ridges of the two-tier ripper (Fig. 3,*c*.).



a)



b)



c)

Fig. 3. Distribution of isolines for the main stress vector $\vec{\sigma}_1$ along the coordinate axes for the two-tier ripper device; the first main stresses in the directions *Ox*, *Oy* and *Oz* ; *a*) - the main stress in the direction of the coordinate - *Ox*; *b*) - the main stress in the direction of the coordinate - *Oy*; *c*) - the main stress in the direction of the coordinate - *Oz*.

As follows from the obtained results, the largest values of the projection of the principal stress $\vec{\sigma}_2$ were observed in the *Oy* direction, and in the other directions they are negligibly small. It follows from Fig. 3 that on the beams of the two-tier ripper they were identical and evenly distributed. In the direction *Oy*, the distribution of isolines is almost identical in all posts. This fact is explained by the fact that the direction *Oy* is not a force direction for a two-tier ripper. Fig. 4 shows the graphs of the change in the deformation of the chisel *1,2,3,4* of the ripper working bodies.

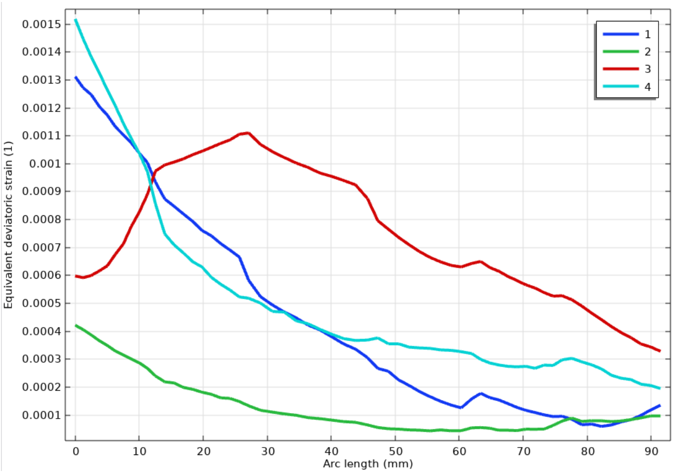


Fig. 4. Change in the deformation of the chisel of the *1,2,3,4* working bodies of a two-tier ripper at the initial stage of loosening.

As the process of loosening the soil with the chisel blade of the two-tier ripper continued, an oscillatory nature of the change in deformation was observed with clearly expressed resonance phenomena for all posts. At different distances of occurrence of resonance phenomena in all posts, significant deepening of the working parts' tips into the soil occurs. This was especially noticeable for the *4*th post, which pulls down the other posts. This fact should be taken into account when assessing the effectiveness of the structure as a whole.

Conclusion.

Thus, we have a simulation model of a tool for cultivating soil for agricultural crops. Using the developed models, it is possible to study various situations during soil cultivation with possible changes in the geometric profiles of the tools under consideration. Since the process considered in this problem is highly complex, the COMSOL package was used for its numerical solution. This software package is a powerful tool widely used by scientists and engineers around the world to model complex physical and engineering processes. One of the reasons for its popularity is the high accuracy of numerical results, which demonstrate good convergence with real experimental data. This makes COMSOL a reliable choice for solving problems that require taking into account many factors and complex relationships.

References

Свечников П. Г.(2013). Модернизация почвообрабатывающих рабочих органов на основе исследования процесса их взаимодействия с почвой // Автореферат диссертации на соискание ученой степени д.октора технических наук: 05.20.01. Челябинск,. 44 с.

Платонов В.А., Чудновский А.Ф.(2004). Моделирование агроклиматических условий и оптимизация агротехники.-Л. Гидрометиздат, -28- с.

И.Р.Рахимов. (2006). Совершенствование рабочих органов машин для основной обработки почвы на основе моделирования процесса, дис. кан. техн. наук: 05.20.01. Челябинск,. - 196с.

J.Listauskas, V.Jankauskasa, A.Zunda et al. (2024). Estimation and modelling the wear resistance of plough points and knife coulters by discrete element method. Wear journal homepage: www.elsevier.com/locate/wear Wear 556-557 (2024) 205508

Afanasiev V.V., Brazhnichenko D.V., Gaiduk V.I., Kalitko S.A., (2018). Information technologies as a driver for the

Аминов Р. И. (2020). Обоснование параметров и разработка культиватора для полосовой обработки почвы и объемного внутрипочвенного внесения удобрений Специальность 05.20.01 – Технологии и средства механизации сельского хозяйства Автореферат дис. канд. техн. наук, Уфа

Boymetov R.I. (2009). Paxtachilikda tuproqqa ishlov berishni minimallashga doir energiya-resurstejamkor kombinatsiyalashgan agregatlar bo'yicha ilmiy tadqiqotlarning asosiy natijalari // Qishloq xo'jaligi uchun yuqori unumli, resurstejamkor texnologiya va texnika vositalari bo'yicha ilmiy tadqiqotlarning natijalari. – Gulbahor, – B. 23-31.

Платонов В.А., Чудновский А.Ф. (2004). Моделирование агроклиматических условий и оптимизация агротехники.-Л. Гидрометиздат,. -28- с.

Казаков Ю.Ф., (2017). Анализ процесса рыхления почвы как системы. Процессы и машины агроинженерных систем 05.20.01 УДК 631.316.022: 303.732.3 © https://cyberleninka.ru/article/n/analiz-protsessa-ryhleniya-pochvy-kak-sistemy/viewer

Мударисов С.Г., (2007). Повышение качества обработки почвы путем совершенствования рабочих органов машин на основе моделирования технологического процесса, дис. докт. техн. наук: 05.20.01. Челябинск,. - 334 с.

Zhiwei Zeng, et al. (2020). Modelling residue incorporation of selected chisel ploughing tools using the discrete element method (DEM) Soil Tillage Res.**(**Mar.**)**

Богданов Е.Н. (2012). О механических свойствах глинистых грунтов. Грунтоведение № 1, с. 62-70.

M. Zangeneh, M. Omid and A. Akram , (2011)**"Parametric and Generative Design Approaches in Agricultural Machinery: A Comparative Study"*(Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, School of Agriculture & Natural Resources, University of Tehran, Karaj, Iran), which appeared in volume 9 issue 3, pp: 661-671, September, of the Spanish Journal of Agricultural Research (accepted 20 June,).

DS Shrestha ·(2001)_Optimization of Plough Design Parameters for Improved Performance Using Parametric Modeling"** https://www.sciencedirect.com/journal/journal-of-agricultural-engineering-research Journal of Agricultural Engineering Research Volume 78, Issue 4, April, Pages 377-389

Alimova F, Saidova M, Ali Bayat A, Primkulov B and Atadjanova M (2020) *Solid StateTechnology* **63(6)** 11876-85

B Sh Primkulov, F A Alimova, M T Saidova, A A Allanazarov and R J Khurramov//(2024). Investigation of operating environments for operating bodies with low tillage// IOP Conf. Series: Earth and Environmental Science 1420 012027.

Prakhar Patidar, Peeyush Soni , Achala Jain, Vijay Mahore, (2002). Modelling soil-rotor blade interaction of vertical axis rotary tiller using discrete element method (DEM) Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, West Bengal 721302, India Contents lists available at ScienceDirect Journal of Terramechanics journal homepage: www.elsevier.com/locate/jterra

Test Results of a Pneumatic Precision Seeder for Bare Cotton Seeds Under Climatic Conditions of Water-Eroded Soils

Mukhayyokhon Saidova[1], Feruza Alimova1 Surayyokhon Khasanova[1]

[1]Tashkent State Technical University, 100095 Tashkent, Uzbekistan;
m.saidova87@mail.ru , feruza.alimova.1961@mail.ru, hasanovasurayyo93@gmail.com

Abstract
This article presents the design and laboratory test results of a pneumatic precision seeder intended for sowing cotton seeds under soil and climatic conditions affected by water erosion. The seeding disk features suction holes with rounded triangular tips and Y-shaped barriers between them. The use of a vertical disk-type pneumatic seeder ensures the optimal grouping of seeds within the holes, enabling reliable suction of various types of agricultural crop seeds regardless of their mass and shape. It also ensures precise grouping in the feeding chamber and their accurate transfer to the furrow zone, resulting in the formation of maximally dense and accurate seed placements in the row. Such a device enhances the functionality of pneumatic seeders and enables high-precision seed placement.

Key Words: *Pneumatic seeder, seed spacing, disc, cotton.*

Introduction
The world is leading in the development of energy-resource technologies and modern technical means for growing cotton. The volume of cotton fiber cultivation on a global scale is 23477 thousand tons, including in India - 6205, China - 5987, USA - 4555, Brazil - 1895, Pakistan - 1785, Australia - 1045, Turkey - 871, Uzbekistan - 838 and Turkmenistan - 296 thousand tons [1-3]. Seeder one of the important tasks is considered to be the improvement and development of new scientifically based energy-resource-saving ones that ensure high quality of work and efficiency. In this regard, certain successes have been achieved in developed foreign countries, including the USA, Turkey, India, China and other countries, with great attention being paid to the development and application of pneumatic sieves that accurately sow seeds [4-6].
Targeted scientific research is being conducted worldwide to develop resource-saving technologies for precision sowing of cotton seeds, to create new models of technical equipment for implementing these technologies, and to improve existing machines in order to enhance their resource efficiency during operation. Within this scope, it is necessary to carry out scientific studies focused on designing a pneumatic seeder capable of sowing three seeds per nest with high precision under various soil and climatic conditions, and to justify its parameters to ensure compliance with agrotechnical requirements.
The seeding rate is determined based on the soil and climatic conditions of the region, sowing time, sowing methods, and other related factors.
In single-seed sowing, one seed is placed in each spot, whereas in nest sowing (group sowing), two or more seeds are dropped into each spot (in fact, even a single-seed spot is referred to as a "cluster").
Cluster sowing is a method where seeds are grouped and sown at fixed distances from one another along the row. This method remains widely used today. The reason is that seeds grouped in clusters emerge more easily through the soil layer compared to singly sown seeds, and the seedlings sprout earlier and more uniformly.
In cluster sowing of cotton seeds, it is required that the number of seeds in each cluster be as uniform as possible. The distance between clusters within a row (typically 15–30 cm) is selected according to cotton cultivation agrotechnics.
The advantage of cluster sowing is that, if rain falls after sowing and a soil crust forms, the grouped seeds in the cluster are more likely to break through the crust. The main drawback of cluster sowing is the higher seed consumption.

Materials and Methods
In addition to general requirements, region-specific sowing requirements adapted to local soil and climatic conditions have also been developed. For instance, in soil-climatic conditions where soil erosion is present, the spring sowing season is often followed by rainfall, which frequently leads to the formation of a crust on the soil surface. In such conditions, single seeds sown individually may not be able to break through the crust and risk remaining underneath it. Therefore, it is advisable to place 2–3 seeds in each nest during sowing [7].

Schemes for nest sowing of cotton seeds are presented in Table 1.1.
Nest Sowing Schemes for Cotton Seeds
Table 1.1

Plant Type	Field Type	Number of Plants (thousand/ha)	Row Spacing (cm)	Sowing Pattern (cm)	Number of Seeds per nest
Cotton	Irrigated land	70-80	60	60x60	3
		90-100	60	60x50	3
		110-130	60	60x45	3
		70-80	60	60x40	2
		110-130	60	60x30	2
		110-130	60	60x25	2
		70-80	90	90x30	2
		90-100	90	90x25	2
		110-130	90	90x20	2

Size Groups of Different Cotton Seed Varieties
Table 2.1

Seed Size Category	Sizes of Graded (Selected) Cotton Seeds, mm		
	Thickness (mm)	Width (mm)	Length (mm)
Average	3,75-5,5	4,5-5,5	8,0-10,5
Short & Large	4,0-6,0	5,0-6,0	7,0-9,5
Small	3,75-5,5	4,5-5,5	7,0-9,5
Long & Large	4,0-6,0	5,0-6,0	8,0-10,5

In cotton-growing regions, the mechanical composition of soils is classified as follows: heavy loam soils make up 71.9%, medium loam soils 20.7%, and light loam soils 7.4%. In autumn, cotton fields are plowed to a depth of 35–40 cm. Deep autumn plowing increases soil permeability and improves leaching of salts when irrigation water is applied during winter. Soil clods naturally break down and soften during winter due to alternating freezing and thawing. As a result, in spring, the upper soil layer retains moisture well and has improved aeration. Before sowing, fields are loosened both in early spring and immediately before planting. Weedy fields are chiseled across the surface to a depth of 10–12 cm. Due to these agrotechnical measures, the 5–10 cm topsoil layer where seeds are sown becomes soft, uniformly textured, and crumbly. The soil layer below 10 cm is slightly compacted but still easily loosened [8].
The set of agrotechnical methods for preparing soil for sowing must be differentiated depending on whether the field was plowed in autumn or early spring. However, in all cases, the 0–10 cm top layer must be sufficiently loose for effective seed placement and healthy plant development. It must also retain moisture accumulated over the fall and winter and be free of weeds.
After heavy rains, a soil crust may form on the surface. Nearly all soils in irrigated farming zones of Central Asia are prone to crusting.

Figure 1. Field area with crust formation on the soil surface.
The main reason for this is the extremely low granularity of these soils and the weak water resistance of soil aggregates. After rainfall or irrigation, the topsoil swells and becomes muddy, and when it dries, it hardens into a crust and cracks. This crust negatively affects soil properties and crop development by reducing water permeability and air exchange. It also accelerates moisture evaporation from the soil (by up to 20–30%). In fields where a thick

crust has formed, seedling emergence may be delayed by 3–5 days, and plant density may be significantly reduced [9-11].

Results and Discussion

The objective of the study is to expand the functionality of the pneumatic feed mechanism for the exact sowing of a predetermined number of bare cotton seeds by a clustered method. The problem is solved by the fact that in the proposed pneumatic feed mechanism (figure2) is a sowing disc with suction cells, which are made in the form of a triangle with rounded tops and with a bridge inside. In this case, the bridge has a Y - shaped form, abuts with its ends against the sides of the triangle.

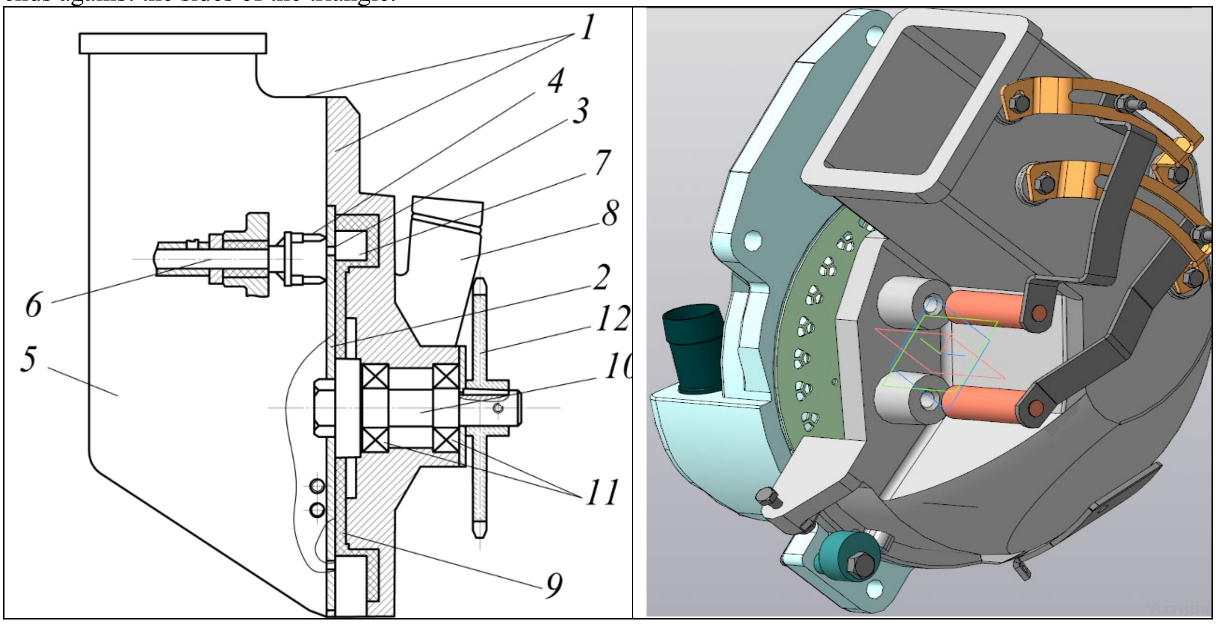
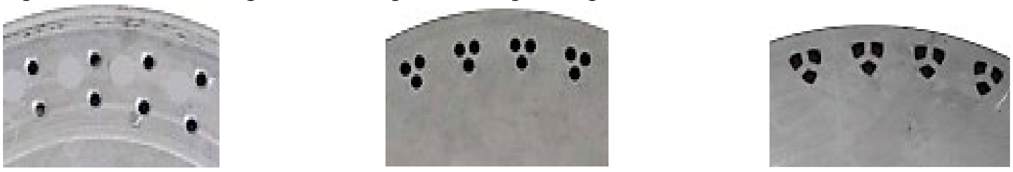
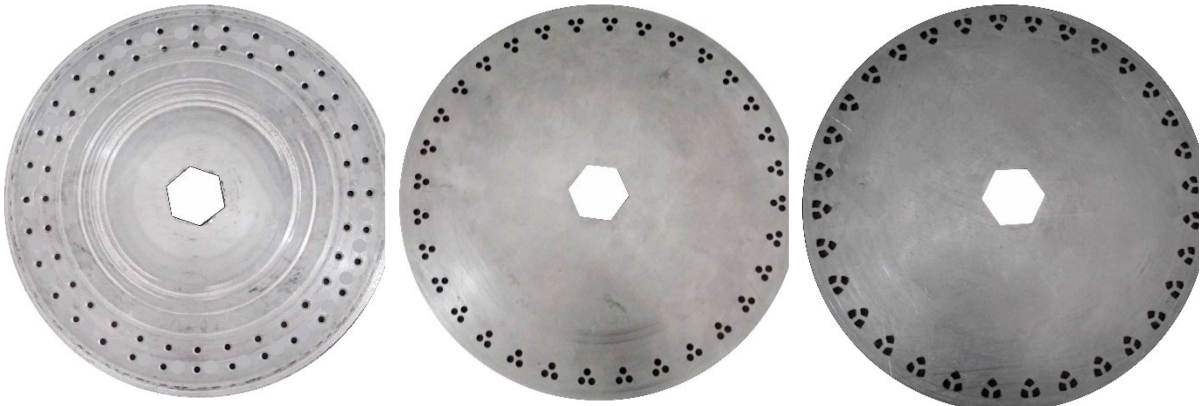


Figure 2. Scheme and 3D model of pneumatic sowing feed mechanism

The proposed pneumatic feed mechanism operates as follows. When creating a vacuum in the rarefaction chamber 7 air passes through the branch pipe 8 to the fan of the planter from the feed chamber 5, cells 3 of the sowing disc 2 and the rarefaction chamber 7; in order to avoid loss of vacuum power, the sowing disc is tightly pressed against the rarefaction chamber with a circular gasket 9. When the sowing disk 2 rotates, mounted on a hexagonal shank of the shaft 10, which rotates on plain bearings 11 when the drive mechanism 12 acts on it, the seeds are carried away by the air flow and in groups (3 pcs. each) stick to the cells 3 with bridges 4 on the sowing disk 2, regardless of their masses and shapes, closing the path for the passage of air and thereby maintaining a constant vacuum in the chamber 7. Due to this rarefaction, a group of seeds lingers in the cells. The shape of the cells is due to the rational form of the group arrangement of 3 seeds, namely the triangle. The tops of the triangle have a rounded shape in order to more reliably suction a group of seeds due to the complete locking of the cells, which eliminates the loss of air flow force and improves the suction capacity of the cells. The presence of a Y - shaped bridge 4 ensures reliable fastening of a seeds group in the cell, eliminates damage to the seeds and clogging of the rarefaction chamber 7. The centers of the cells 3 of the sowing disc are located on the same circle. The rotating disc 2 carries the groups of seeds beyond the vacuum. In the lower part of housing 1, by removing the vacuum, groups of seeds move away from the cells and, under the action of gravity, exactly 3 pieces fall into a narrow groove formed by the coulter.

Based on the above, experiments were conducted on the existing and improved planting discs of the PS-4 pneumatic seeder. Figure 3 shows pictures of planting discs.





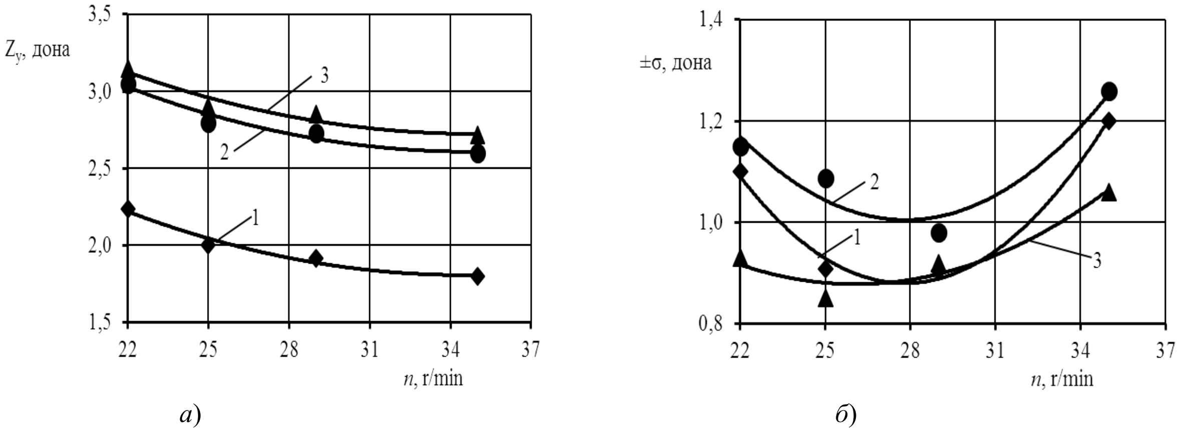
a b c

Figure 3. Seeding discs with different hole configurations

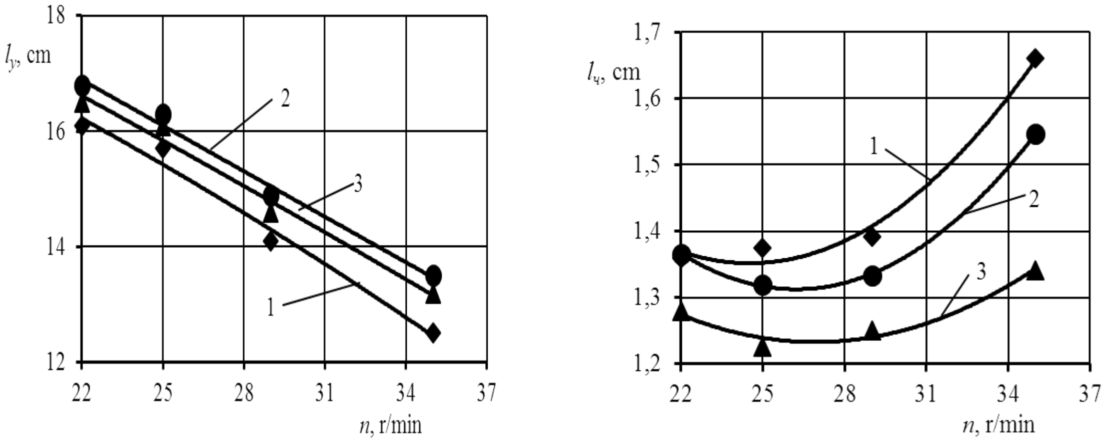
1.Variant 1: a seeding disc with two circular holes (Figure 3a),
2.Variant 2: a seeding disc with three circular holes (Figure 3b),
3.Variant 3: a seeding disc with triangular suction holes having rounded tips and a Y-shaped barrier between them (Figure 3c).

The experiments were conducted at the seeding disk rotation speeds of 22, 25, 29 and 35 r/min. The results of the experiments are shown in Fig. 4. Fig. 4, a shows that when the seeding disk rotation speed changed from 22 r/min to 35 r/min, the number of seeds falling into the cell decreased from 2.24 to 1.80 seeds in the disk of variant 1, from 3.05 to 2.06 seeds in the disk of variant 2, and from 3.15 to 2.71 seeds in the disk of variant 3. The reason for this is that the seeds are not sufficiently absorbed into the cells. This is a consequence of the lack of time necessary for reliable absorption of the seeds into the cells (Fig. 4, a). Analyses show that the number of seeds falling into the cells is inversely proportional to the number of rotations of the sowing disc. The reason for this is that when the number of turns increases, the seed does not stick tightly to the hole and falls out of the nest when other seeds touch it. This leads to the fact that the nest remains empty. As a result, the number of seeds sucked into the sucking holes decreases. In this case, the standard deviation of the number of seeds falling into the nest changes according to the law of a parabola depending on the number of turns (Fig. 4, b). The distance between seeds in the cells decreased as the rotation speed of the planting discs increased. This is because an increase in the number of rotations reduces the suction capacity of the holes in the disc. Therefore, it is necessary to select the rotation speed of the disc and the number of cells in the disc in such a way that the required planting quality is ensured at a certain speed of the seeder's movement.

In the experiments conducted, planting accuracy decreased along a curve as the planting speed increased. The reliability of cottonseed suction into the hole is negatively affected by the short duration of the process within the "hole-vacuum-seed" system and the interaction forces between cottonseeds in the seed chamber. The unique characteristics of the suction holes in the Variant 3 disc help ensure reliable grouping and holding of cottonseeds in the cell and their delivery to the separation zone under vacuum.



а) *б*)



c) d)

1 – Seeding disc with two circular holes 2 – seeding disc with three circular holes 3 – seeding disc with triangular suction holes having rounded tips and a Y-shaped barrier between them

Figure 4: The effect of the planting disc's rotation speed on: (a) the number of seeds in the cells, (b) its mean square deviation, (c) the distance between cells, and (d) the elongation of the cells.

From the graphs, it's clear that the number of cottonseeds falling into the holes met agrotechnical requirements when the rotation speed of all discs varied between 22-30 r/min. The width and elongation (i.e., clustering) of the cottonseed cells were higher in Variant 3.

Conclusions

1.Utilizing a vertical disc pneumatic planting apparatus designed with suction cells on the planting disc that are triangular with rounded ends and feature a Y-shaped barrier between them ensures: Rational arrangement of groups in the cells. Reliable suction of various agricultural crop seeds in groups into the cells, regardless of their mass and shape. Precise grouping of seeds in the feeding chamber and their transfer to the furrow opener zone. Stable formation of maximally clustered, accurate cells in the planted furrow. Such apparatuses serve to expand the functionality of pneumatic seeders and enable high-precision cluster planting of seeds.

2.To ensure the required suction of seeds into the cells of a planting disc designed for cluster planting and their removal from the general mass, the following parameters are recommended for the triangular cell ends: Radius of rounding: 1.64 mm Width: 6.58 mm Height: 6.13 mm Pitch of suction cells: 18.72 mm Circumferential speed of the planting disc (at the center of suction cells): 0.27 m/s Diameter of the planting disc (at the center of suction holes): 195 mm Full diameter: 231 mm Rotation speed of the planting disc: 0.44 rev/s (26.4 rev/min) Angular velocity: 2.81 rad/s Number of suction cells on the planting disc: 32 units

3.To form clustered cells at the bottom of the planting furrow at a given movement speed, the installation height of the planting apparatus from the furrow bottom and the seed drop angle should be as small as possible.

4.When the rotation speed of the planting disc was between 22-30 r/min, the quality indicators for cottonseed planting met agrotechnical requirements.

5.With the planting disc featuring triangular suction cells with rounded corners and an internal Y-shaped barrier (Variant 3), planting accuracy was within the normal range when the seeder's movement speed was from 1.95 m/s to 2.76 m/s.

6.The force required to separate cottonseeds from the disc holes was higher in the planting apparatus with triangular suction cells (rounded corners, Y-shaped internal barrier) compared to other variants.

References

Xiaorui, P. E. N. G., Jian, W. A. N. G., & Bin, H. U. (2017). Design and experiment of pneumatic cylinder array precision seed-metering device for cotton. Nongye Jixie Xuebao/Transactions of the Chinese Society of Agricultural Machinery, 48(12).

Javellonar, R. P., Delaraga, L. V., & Alegato, O. R. (2016). Design, development and evaluation of a disc-type corn seeder. Ilocos Journal of Science, 61.

Kathirvel, K., Reddy, A., Manian, R., & Senthilkuamr, T. (2005). Performance evaluation of planters for cotton crop. AGRICULTURAL MECHANIZATION IN ASIA AFRICA AND LATIN AMERICA, 36(1), 61.

Veerangouda, M., Maski, D., Desai, B. K., & Doddagoudar, S. R. (2020). Study on some engineering properties of cotton seeds in relation to the development of a tractor operated seed dibbler. Journal of Pharmacognosy and Phytochemistry, 9(5), 1836-1839.

Ramesh, B., Reddy, B. S., Veerangoud, M., Anantachar, M., Sharanagouda, H., & Shanwad, U. K. (2015). Properties of cotton seed in relation to design of a pneumatic seed metering device. Indian Journal of Dryland Agricultural Research and Development, 30(1), 69-76.

Byler, R. K. (2003, June). Moisture restoration for seed cotton, two approaches. In Proc. Beltwide Cotton Conf (pp. 767-771).

Saidova, M., Tursunbaev, S., Boltaeva, M., Ismoilov, T., & Gilijova, A. (2024). Analysis of a pneumatic seeder equipped with an improved planting disc. BIO Web of Conferences, 105. https://doi.org/10.1051/bioconf/202410501024

Saidova, M., Tursunbaev, S., Boltaeva, M., & Isakulova, N. (2024). Comparison of pneumatic sowing machines by the number of seeds in the slots of the discs and the distance between the slots. BIO Web of Conferences, 105. https://doi.org/10.1051/bioconf/202410501004

Djiyanov, M., Tadjibekova, I., Temirkulova, N., & Kholmuradov, O. (2024). Development of Rational Composition of Assessment Indicators of Small Technical Tools. In Lecture Notes in Networks and Systems (Vol. 733). https://doi.org/10.1007/978-3-031-37978-9_55

Saidova, M., Alimova, F., Tursunbaev, S., Kulmuradov, D., & Boltaeva, M. (2023). Influence of the shape of the disc slots of the seeder on the suction force of the vacuum for precise sowing of seeds. IOP Conference Series: Earth and Environmental Science, 1284(1). https://doi.org/10.1088/1755-1315/1284/1/012014

Feruza Alimova, Mukhayyokhon Saidova, Ergash Boboniyozov, and Beknur Mirzayev (2024) Analysis of the state of mechanized sowing of rice in seedlings BIO Web of Conferences , 01032 (2024) I-CRAFT-2023 85 https://doi.org/10.1051/bioconf/20248501032
https://scholar.google.com/scholar?oi=bibs&cluster=8993652941648425238&btnI=1&hl=ru

Strawberry Cultivation Using Smart Systems

İlbilge Oğuz[1*], Halil İbrahim Oğuz[2],Osman Gökdoğan[3], Nesibe Ebru Kafkas[1]

[1]*Department of Horticulture, Faculty of Agriculture, Çukurova University, TR-01330 Adana Balcali, Türkiye
[2]Department of Horticulture, Faculty of Agriculture, Adıyaman University 02040, Adıyaman, Türkiye
[3]Department of Agricultural Machinery and Technologies Engineering. Faculty of Agriculture, Isparta University of Applied Sciences, Isparta, Türkiye
*Corresponding author: ilbilge94@gmail.com

Abstract

In countries with advanced precision agriculture, IoT-supported monitoring and irrigation systems are widely used in strawberry cultivation. These systems monitor soil moisture, temperature, and humidity, offering remote access via ThingSpeak. Measurement reliability is validated with commercial meters, and user acceptance is high (over 80%) based on TAM surveys and interviews. Cloud-based systems, specifically Farm as a Service (FaaS) integrated systems, have been developed for comprehensive plant disease analysis and accurate prediction. These systems manage IoT devices, collect environmental and growth data, and perform analyses. The IoT-Hub network model ensures reliable data transfer even in harsh environments. This integration promotes widespread technology adoption in agriculture, enabling disease monitoring and prediction for strawberries, which fosters nature-friendly production. The need to preserve the quality of delicate strawberries drives farmers selling directly to consumers to adopt smart systems for product quality and health control. This has led to increased use of cloud-based smart irrigation and automation systems. In greenhouse strawberry cultivation, a new system uses an Arduino microcontroller, GSM module, and sensors to continuously monitor the environment and soil moisture. Users can control parameters via SMS, receiving notifications and activating the water pump when levels are exceeded. These systems provide effective remote greenhouse management. The study aims to enhance strawberry production efficiency, quality, and sustainability, optimize resource use, reduce costs through smart irrigation and climate control, and establish an environmentally friendly, data-driven production model.

Keywords: *Strawberry, Smart farming, remote sensing, Arduino, automation*

Introduction

The agricultural sector is confronted with a multitude of challenges on a global scale, encompassing population growth, climate change, water scarcity, and the sustainable utilization of natural resources. These issues are especially evident in the context of fruit cultivation, where production exhibits a high degree of sensitivity to environmental conditions. In this context, there is an increasing need to move beyond traditional agricultural methods and adopt more efficient, sustainable, and technology-driven solutions. In recent years, the integration of technologies such as the Internet of Things (IoT), remote sensing, artificial intelligence (AI) and edge computing into agricultural production has led to significant developments, particularly in the cultivation of high value-added products such as strawberries (*Fragaria x ananassa*). The strawberry (*Fragaria × ananassa*) is a widely consumed product, both in its fresh state and as a processed food, and has high economic value. However, the cultivation of strawberries is highly sensitive to various environmental factors, including temperature, humidity, soil moisture, diseases, and pests. Consequently, meticulous observation and prompt intervention are imperative throughout the production process. Smart farming systems have been shown to optimise production processes by enabling the real-time collection and analysis of environmental data, and the subsequent automatic decision-making processes based on this data (Kim et al., 2018; Zhang et al., 2021).

Varela-Aldás et al. (2024) conducted a study examining the adoption levels of IoT-based systems among different user groups. The study emphasized that user-friendly interfaces play a critical role in the success of such systems. This finding underscores the significance of technological infrastructure, as well as user training, trust in technology, and adaptability to local requirements. A significant challenge in the context of strawberry production pertains to the timely and accurate diagnosis of plant diseases. Kim et al. (2018) demonstrated the feasibility of early disease diagnosis through the utilisation of sensor data and machine learning algorithms. These systems empower producers to intervene in a timely manner, thereby reducing yield losses and minimising pesticide use, thus contributing to environmental sustainability. The approach proffers considerable benefits with regard to food safety. In the context of greenhouse strawberry production, effective irrigation management is of paramount importance.

As reported by Htet et al. (2021) and Angelopoulos et al. (2020), smart irrigation systems have the capacity to be automatically adjusted according to seasonal variability. Furthermore, these systems, when supported by edge computing technologies, have been shown to significantly reduce data processing times. Consequently, water resources will be utilised more efficiently, energy consumption will be significantly reduced, and production costs will be lowered considerably. Furthermore, these systems will empower producers to implement optimised irrigation strategies without the necessity for manual decision-making. In their study, Elenzano et al. (2021) examined how smart systems can provide solutions to the climatic challenges of strawberry cultivation in low-lying areas. The study, titled 'Smart Farming for Lowland Strawberry (*Fragaria x ananassa*) Production', was published in the academic journal. It was asserted that these systems optimise the production environment by monitoring microclimate conditions and enable stable production throughout the year. It is argued that this situation will also be extremely beneficial for countries such as Türkiye, which have different climate zones and the potential to geographically expand strawberry production. Moreover, Marques et al. (2024) conducted a study that demonstrated the potential of remote sensing technologies in the context of fruit orchards, offering insights into various aspects such as plant health, growth status, and yield estimation. These technologies facilitate the monitoring of extensive areas of strawberry fields, thereby enabling producers to make decisions at a macro level. The argument is made that tools such as satellite imagery, drone-based observation systems, and hyperspectral cameras can provide highly accurate information about the overall condition of production areas. The present paper offers a thorough evaluation of the utilisation of smart systems in strawberry cultivation, with particular reference to the extant literature. The effects of the integration of IoT-based monitoring systems, AI-supported disease prediction models, smart irrigation solutions and remote sensing technologies on production efficiency, sustainability and user acceptance will be discussed. Furthermore, an evaluation is conducted of the current state of strawberry production in Turkey and the potential for local adoption of these technologies. In this context, smart systems are regarded not only as a technological innovation but also as a strategic instrument for agricultural development and food security.

The Importance of Smart Agriculture In Strawberry Cultivation

The AgroTec 4.0 intelligent agricultural system was developed to enhance the efficiency of strawberry production in the Andean region of Ecuador. This system employs edge computing technology to optimise strawberry cultivation, particularly in greenhouse environments. The objective of this study was to evaluate the system's impact on efficiency by comparing strawberry production areas where AgroTec 4.0 was utilised and those where it was not, under the same greenhouse conditions. The system was designed with three key principles in mind: user-friendliness, cost-effectiveness and ease of implementation. These design principles were intended to ensure the system's suitability for use by low-income farmers who may have limited educational opportunities. Farmers who utilised the system observed a 15% increase in strawberry yield in their greenhouses. When the yield per square metre is considered, the control greenhouse yielded 5.0 kg per square metre, while the greenhouse using AgroTec 4.0 yielded 5.75 kg/m². Water usage was reduced by 20%. The control greenhouse utilised 80 litres of water per square metre, whereas the system reduced this to 64 litres. The system provides real-time decision support to farmers by analysing environmental data, including soil moisture, temperature, and light. The system's edge computing infrastructure processes data locally without sending it to the cloud, thereby reducing latency and eliminating dependence on internet connectivity. The system's adaptability to diverse production scales is facilitated by the use of low-cost sensors and a modular design. This study demonstrates how smart agriculture technologies can be an effective tool for sustainable agriculture practices, particularly in developing regions. AgroTec 4.0 has been demonstrated to contribute to environmental sustainability by increasing productivity and optimising natural resource use (Abdo-Peralta et al., 2024).

Strawberries are the most commercially produced and consumed fruit worldwide. Their production and consumption are increasing due to their unique aroma, taste and biochemical properties. The genus to which the strawberry belongs is Fragaria, which is itself part of the Rosaceae family, which is more commonly referred to as the 'rose family'. The provenance of the strawberry is traditionally attributed to South America, particularly Chile. It is evident that the wild F. vesca species is utilised by people residing in Asia, Europe, and America. In various geographical regions, including Japan, North China, Manchuria, Europe, Siberia, and America, there exist diverse eco-geographical areas in which alternative species are found to be concentrated. Despite its provenance in the Pacific Northwest region of North America, F. ananassa is now cultivated on a global scale. The strawberry (*Fragaria × ananassa*) is one of the most widely cultivated fruit species, grown in nearly every country, including high-altitude areas of tropical, subtropical and temperate climate zones. In this section, we aim to provide new perspectives on the future of strawberry cultivation techniques by analysing current academic studies on strawberry production (Marques et al., 2024).

Elashmawy and Uysal (2023) examined the use of machine learning models supported by data obtained from soil sensors in strawberry production within the scope of smart farming applications. They defined the second phase of a system that aims to predict the physicochemical properties of strawberries (e.g., colour and taste) at harvest time through the precise monitoring and management of soil conditions. The study involved the collection of real-time data from the soil of a commercial strawberry farm using sensor networks that had been installed for this purpose. These sensor networks were connected to cloud-based systems, which then analysed the data in order to predict the quality characteristics of the strawberries. In their work, they conducted analyses using both empirical and statistical methods, such as artificial neural networks and Gaussian process regression. The findings of the study indicated that when attempting to predict quality characteristics such as strawberry colour, either in isolation or in conjunction with soluble solid content (sweetness), the level of prediction accuracy achieved was 9% and 14%, respectively. This level of accuracy is pivotal for the establishment of a foundation for future data-driven soil management and optimisation of resources. This sustainability and automation system functions with fully automated soil conditioning mechanisms, thereby supporting sustainable and high-quality strawberry production. Machine learning algorithms are utilised to analyse soil data, with the objective of optimising decisions regarding factors such as the timing of harvest, the management of inputs, and the quality of the product. It has been demonstrated that such studies are not confined to the domain of strawberry production; rather, they can be readily adapted to other specialised crops. As data-driven decision-making processes become more widespread in agriculture, such systems offer significant advantages both economically and environmentally.

The efficacy of an edge computing and Internet of Things (IoT)-based smart farming system in combating diseases and environmental stress factors encountered in strawberry production was investigated. It is well established that strawberries exhibit a high degree of sensitivity to environmental changes, including temperature and humidity, as well as pests, due to their delicate structure. Consequently, pesticides and agricultural chemicals are utilised extensively during the production process. This scenario has the potential to exert a detrimental effect on both the quality of the product and the surrounding environment. The system utilised in the study performs processes such as the collection, analysis, prediction, and detection of diseases using edge computing technology. The IoT platform analyses environmental and plant data by combining different monitoring services into a single digital agriculture platform. The system facilitates low-energy data transmission over long distances by employing the LoRa communication protocol. Machine learning algorithms have been developed for the purpose of detecting outliers in data collected from the environment, thereby ensuring the reliability of the information provided to the user. The system utilises a computer vision model, based on the YOLO v5 architecture, to detect the seven most prevalent diseases in strawberries in real time. The accuracy rate of this model has been documented as 92%, which is considered to be highly effective in terms of facilitating early diagnosis and intervention. The system was subjected to empirical scrutiny through its implementation on a real strawberry farm. Consequently, the implementation of the application has yielded a number of advantageous outcomes, including the facilitation of early disease diagnosis, the mitigation of environmental stress, and the enhancement of production efficiency. It was also observed that the system's modular design facilitates its adaptation to diverse climatic and production conditions. This study demonstrates the efficacy of smart agriculture technologies in the cultivation of sensitive crops such as strawberries, thereby contributing significantly to environmental sustainability, productivity, and food safety (Cruz et al., 2022). The mounting global demand for food in agriculture gives rise to the need for innovative applications in terms of environmental sustainability and efficiency. In this context, although there has been success in the application of artificial intelligence (AI) technologies in areas such as plant stress detection and growth monitoring, research in the field of growth stage classification in special products such as strawberries has not yet been sufficiently extensive. An AI-based system, designated SmartBerry, has been developed to accurately classify growth stages and refine nutrient management in strawberry cultivation. The primary objective of the system is to accurately identify the different growth stages of the strawberry plant and to meet the specific nutrient requirements of each stage in a timely manner. This approach is critical for both increasing yield and improving fruit quality. The primary deficiencies identified by researchers in the extant literature pertain to the following: the absence of readily available and high-quality data sets, the utilisation of obsolete methodologies, the paucity of model comparisons (benchmarking), and the dearth of data sets and methods. In order to address these shortcomings, a high-quality image dataset has been created, covering seven different growth stages in a greenhouse environment. This dataset, collected under a range of light and environmental conditions, provides a substantial resource for model training. In the study, a range of deep learning models were evaluated, and the EfficientNetB7 model was identified as the most accurate, achieving an accuracy of 83.7%.

As a result, it clearly demonstrates the potential of AI-enabled systems to optimise nutrient management in strawberry farming. The importance of nutrient management The paper emphasises that nutrient management is a fundamental element in modern agriculture. Plants have different nutrient needs at each growth stage and meeting these needs at the right time directly affects both crop quality and soil health. While over-fertilisation degrades soil structure, under-fertilisation leads to economic losses. Therefore, stage-specific and timely nutrient application is indispensable for sustainable agriculture (Darlan, et al., 2025).

This review article comprehensively examines the most recent developments in this field, focusing on deep learning techniques used in strawberry cultivation, especially in greenhouse environments. The strawberry (*Fragaria × ananassa* Duch.) is widely regarded as the 'queen of fruits'. It is considered beneficial for cardiovascular health and has been shown to assist in balancing blood sugar levels due to its high vitamin C and antioxidant content. Its consumption is pervasive on a global scale, primarily due to its nutritional value, flavour and affordable cost. The text draws attention to the importance of precision agriculture practices, which have been demonstrated to provide higher yield and quality in comparison to traditional agricultural methods. In this context, the integration of deep learning models, such as convolutional neural networks (CNNs), which are extensively utilised in the domain of computer vision, into strawberry agriculture has been demonstrated to enhance production processes, rendering them more efficient and sustainable. However, the authors emphasise that a comprehensive and systematic review of deep learning applications in strawberry agriculture is absent from the extant literature. The following aspects are discussed in detail: the application of deep learning models in strawberry agriculture; the success of these models in applications such as growth stage classification, disease detection and maturity detection; and the improvement of models through fine-tuning techniques. The characteristics and limitations of the data sets used are also examined. Moreover, the challenges faced by research models in real-time applications, and the manner in which these challenges can be surmounted, are also discussed (Yang and Kim, 2023).

In the context of horticultural production, particularly in the domains of plant phenotyping (the measurement of plant characteristics) and management processes, the utilisation of remote sensing (the acquisition of information about the environment through electromagnetic or infrared energy) and machine learning (the process through which machines can learn or improve their performance through experience) holds particular significance. These technological advancements have had a substantial impact on the cultivation of cherries. In the domain of plant breeding and agricultural management, a substantial impediment has been identified in the necessity for expeditious and precise measurement of plant characteristics. The acquisition of data pertaining to substantial plant populations is of paramount importance for the purposes of monitoring plant health and conducting genetic analysis. At this juncture, state-of-the-art phenotyping technologies, remote sensing and machine learning are providing significant benefits. It has been posited that the integration of a range of sensor types (e.g. high-resolution RGB, multispectral, hyperspectral, chlorophyll fluorescence and LiDAR) in conjunction facilitates the evaluation of various morphological, structural, biophysical and biochemical characteristics.

Concurrently, the fields of computer vision and machine learning have witnessed the development of sophisticated methodologies for the extraction of significant biological information from such image data. The primary domains in which remote sensing and machine learning technologies are employed in the context of strawberry agriculture are delineated as follows: The detection of fruit and flowers, the assessment of maturity, quality, and intrinsic fruit characteristics, the analysis of fruit shape and yield prediction, the characterisation of leaf and vegetation characteristics, the identification of water stress, the detection of diseases and pests, and their classification, provide a framework of significant importance to strawberry producers and researchers. This framework enables the optimisation of the production process and the monitoring of plant health. The subsequent discussion encompasses prospective research opportunities and directions, with the objective of facilitating more widespread and effective utilisation of these technologies in the context of strawberry agriculture. In particular, the development of artificial intelligence-supported decision support systems, automation of data collection processes and the dissemination of real-time monitoring systems are identified as the primary areas that will facilitate digitalisation in strawberry agriculture (Zheng et al., 2021).

The use of Internet of Things (IoT)-based technologies to increase productivity and sustainability in strawberry farming has been introduced in many countries. The limitations of traditional farming methods, especially problems such as climate change, decreasing water resources and lack of labour force, push farmers to seek more innovative and technological solutions. In this context, smart agriculture applications are of great importance, especially in the production of sensitive fruits such as strawberries. The integration of IoT devices (soil moisture sensors, temperature and light sensors, automatic irrigation systems, etc.) into strawberry orchards is being addressed and farmers can remotely monitor and manage their agricultural activities with real-time data. Thus, water and fertiliser use is optimised, early detection of diseases is possible and overall product quality is improved. The results of an IoT-based system piloted in a specific region can also be shared. It can be stated that this system provides 20-30% higher yields compared to traditional methods, reduces water consumption and reduces the need for labour. Recent studies emphasise the importance of digital transformation in strawberry agriculture and show how IoT technologies can revolutionise agricultural production (Sari, et al., 2024).

A study conducted in Italy comprehensively investigates the effects of sensor-based fertigation management on resource use efficiency and crop performance in soilless strawberry cultivation. In the context of the mounting imperative for the sustainable utilisation of water and nutrient resources in agricultural production, this research offers a comparative analysis of the efficacy of sensor-assisted systems and conventional methods. In this research, a comparison was made of two different fertigation strategies in an open system hydroponic strawberry production in Italy. The first system is a traditional timer-based (TB) system, while the second is a sensor-based (SB) system. In the SB system, wireless sensors (Teros 12) were utilised to assess the moisture and electrical conductivity levels of the substrate (growing medium). The automation of irrigation and fertilisation decisions was enabled by the deployment of sensors, which facilitated the real-time monitoring of data and the subsequent determination of optimal intervention times. The findings indicate that the SB system utilised 38% less nutrient solution and 26% less total water in comparison to the TB system. This substantial reduction in resource consumption did not result in a decline in crop quality; in fact, total and marketable yields were higher in the SB system. This finding indicates that the utilisation of sensors in management systems confers benefits that extend beyond environmental sustainability, encompassing economic efficiency as well. Furthermore, the SB system demonstrated a 46% increase in water use efficiency and a 74% increase in nutrient use efficiency. The findings of this study demonstrate that the implementation of sensor-assisted fertigation can enhance the sustainability and efficiency of agricultural production, particularly in regions characterised by constraints in water and fertiliser resources. In conclusion, the study demonstrates that the implementation of sensor-based fertigation management in the context of soilless strawberry production confers substantial benefits, both in terms of environmental impact and economic efficiency. The dissemination of such technologies has the potential to make a significant contribution to the agricultural sector, particularly in addressing challenges such as climate change and water scarcity (Bonelli et al., 2024).

Recent research findings provide substantial evidence that the implementation of smart agricultural technologies in strawberry production is both effective in increasing productivity and significantly contributes to environmental sustainability. These technologies offer innovative solutions to the key challenges faced by traditional farming methods, including labour shortages, limited resources, disease management and climate change.

Results and Discussion

The implementation of smart farming systems has been demonstrated to result in a substantial enhancement in yield per square metre in strawberry greenhouses, with certain studies indicating an increase of up to 15%. This development is accompanied by notable economic advantages. Concurrently, it is possible to achieve savings of up to 20% in critical resources, including water usage. In particular, sensor-based fertigation systems have been shown to have the capacity to significantly reduce nutrient solution and water consumption, while concomitantly increasing productivity without compromising product quality. This approach offers significant benefits, including enhanced environmental sustainability and reduced input costs for farmers.

These systems provide farmers with real-time decision support by means of instant analysis of environmental data, including soil moisture, temperature and light. Machine learning models, supported by data from soil sensors, have been shown to be capable of predicting physicochemical properties of strawberries, including colour and sweetness, with a high degree of accuracy at the point of harvest. Consequently, the timing of harvesting and the management of product quality can be optimised to increase market value.

Furthermore, edge computing and Internet of Things (IoT) based systems have been demonstrated to possess the capability to detect common diseases in strawberries with a high degree of accuracy. The implementation of this early detection capability has been demonstrated to result in a reduction in the utilisation of pesticides, thereby enhancing the quality of crops and reducing the environmental impact. The processing of data locally by such technologies has been demonstrated to reduce latency and eliminate reliance on internet connectivity, rendering them particularly suitable for farmers in rural and infrastructure-limited areas.

The integration of deep learning models and artificial intelligence has demonstrated significant success in domains such as the classification of the growth stages of strawberries, the detection of diseases, and the determination of fruit maturity. The utilisation of remote sensing and machine learning techniques has proven to be a versatile approach, finding application in a multitude of domains. These include, but are not limited to, the identification of fruit and flowers, the estimation of crop yield, the assessment of water stress, and the identification of diseases in agricultural settings.

A number of recommendations stand out for the sustainability and popularisation of progress in this area:

Technology Dissemination and Accessibility: It is of great importance that the developed user-friendly, economical and easily applicable systems are made available to farmers, especially those with low income and limited education. In this direction, adoption of technology should be accelerated by developing government supports, training programmes and appropriate financing models. The use of technologies such as edge computing can enable smart agriculture applications to become widespread even in regions with inadequate internet infrastructure.

Enrichment and Standardisation of Data Sets: For AI models to be more robust and generalisable, larger, diverse and high quality image and sensor datasets covering different climatic conditions, geographical regions and strawberry varieties need to be created. Future work should focus on creating common databases to facilitate the sharing of these datasets.

Continuity of Model Development and Integration: Continue to develop more complex and customised deep learning models for different growth stages, physiological stress states and disease symptoms of strawberries. By integrating data from different types of sensors, more comprehensive plant monitoring systems should be created, laying the foundation for autonomous agricultural robots and UAV-based spraying systems.

The development of real-time decision support systems: The development and dissemination of AI-enabled decision support systems should be accorded priority. These systems have the capacity to facilitate immediate and optimised decision-making processes by farmers, pertaining to issues such as soil moisture, nutrient requirements, disease risk and harvest timing. The development of integrated systems with fully automated soil conditioning mechanisms is recommended for the purpose of sustainable and high-quality strawberry production.

Increasing Economic and Environmental Impact Analyses: It is recommended that further studies be conducted on the long-term economic returns and environmental benefits (water savings, fertiliser and pesticide reduction, carbon footprint reduction) of smart farming systems. Such studies would be more comprehensive and transparent. Evidence of this nature would be persuasive to farmers and policymakers, encouraging widespread adoption of technologies.
These recommendations provide a roadmap to fully realise the potential of digital transformation in strawberry agriculture and ensure a sustainable, efficient and profitable production process.

Declaration of Competing Interest
The authors report no declarations of interest.

References

Abdo-Peralta, P., García-Pumagualle, C., Carrera-Silva, K., Frey, C., Rosero-Erazo, C. R., Ortega-Castro, J., ... & Toulkeridis, T. (2024). Implementation of an enhanced edge computing system for the optimization of strawberry crop in greenhouses: a smart agriculture approach. Agronomy, 14(12), 3030. https://doi.org/10.3390/agronomy14123030

Angelopoulos, C. M., Filios, G., Nikoletseas, S., and Raptis, T. P. (2020). Keeping data at the edge of smart irrigation networks: A case study in strawberry greenhouses. Computer Networks, 167, 107039. https://doi.org/10.1016/j.comnet.2019.107039

Bonelli, L., Montesano, F. F., D'Imperio, M., Gonnella, M., Boari, A., Leoni, B., & Serio, F. (2024). Sensor-based fertigation management enhances resource utilization and crop performance in soilless strawberry cultivation. Agronomy, 14(3), 465. https://doi.org/10.3390/agronomy14030465

Cruz, M., Mafra, S., Teixeira, E., and Figueiredo, F. (2022). Smart strawberry farming using edge computing and IoT. Sensors, 22(15), 5866. https://doi.org/10.3390/s22155866

Darlan, D., Ajani, O. S., An, J. W., Bae, N. Y., Lee, B., Park, T., and Mallipeddi, R. (2025). SmartBerry for AI-based growth stage classification and precision nutrition management in strawberry cultivation. Scientific Reports, 15(1), 14019. https://doi.org/10.1038/s41598-025-97168-z

Elashmawy, R., and Uysal, I. (2023). Precision agriculture using soil sensor driven machine learning for smart strawberry production. Sensors, 23(4), 2247. https://doi.org/10.3390/s23042247

Elenzano, J. J., Antonio, J. W. A., Cariaga, R. M., Vega, C. A. C. D., Gomez, R. M. V., Oranza, J. C., and Samaniego, M. L. B. (2021). Smart farming for lowland strawberry (Fragaria x ananassa) production. Turkish Journal of Computer and Mathematics Education, 12(3), 1797-1804.

Htet, Y., Oo, H. K., and Zin, T. T. (2021). Smart irrigation: an intelligent system for growing strawberry plants in different seasons of the year. ICIC Express Letters, 12(4), 359-367.

Kim, S., Lee, M., and Shin, C. (2018). IoT-based strawberry disease prediction system for smart farming. Sensors, 18(11), 4051. https://doi.org/10.3390/s18114051

Marques, P., Pádua, L., Sousa, J. J., and Fernandes-Silva, A. (2024). Advancements in remote sensing imagery applications for precision management in olive growing: A systematic review. Remote Sensing, 16(8), 1324. https://doi.org/10.3390/rs16081324

Sari, K., Hidayati, R., Nirmala, I., and Ristian, U. (2024). Empowerıng Strawberry Cultıvatıon: Harnessıng The Potentıal Of Iot-Based Technology In Smart Farmıng. Jıtk (Jurnal Ilmu Pengetahuan Dan Teknologi Komputer), 10(1), 53-61.

Varela-Aldás, J., Gavilanes, A., Velasco, N., Del-Valle-Soto, C., and Bran, C. (2024). Acceptance of an IoT System for Strawberry Cultivation: A Case Study of Different Users. Sustainability, 16(16), 7221. https://doi.org/10.33480/jitk.v10i1.4162

Zhang, C., Valente, J., Kooistra, L., Guo, L., and Wang, W. (2021). Orchard management with small unmanned aerial vehicles: A survey of sensing and analysis approaches. Precision agriculture, 22(6), 2007-2052. https://doi.org/10.1007/s11119-021-09813-y

Zheng, C., Abd-Elrahman, A., and Whitaker, V. (2021). Remote sensing and machine learning in crop phenotyping and management, with an emphasis on applications in strawberry farming. Remote Sensing, 13(3), 531. https://doi.org/10.3390/rs13030531

Yang, J. W., and Kim, H. I. (2023). An overview of recent advances in greenhouse strawberry cultivation using deep learning techniques: A review for strawberry practitioners. Agronomy, 14(1), 34. https://doi.org/10.3390/agronomy14010034

Using of Digital Agriculture, Machine Learning, Remote Sensing and Smart Approaches in Fruit Orchards

Halil İbrahim Oğuz[1], İlbilge Oğuz[2],Osman Gökdoğan[3]

[1]*Department of Horticulture, Faculty of Agriculture, Adıyaman University 02040, Adıyaman, Türkiye
[2]Department of Horticulture, Faculty of Agriculture, Çukurova University, TR-01330 Adana Balcali, Türkiye
[3]Department of Agricultural Machinery and Technologies Engineering. Faculty of Agriculture, Isparta University of Applied Sciences, Isparta, Türkiye
*Corresponding author: hioguz64@gmail.com

Abstract

In recent years, advances in remote sensing technologies have made considerable progress in the monitoring of orchards. These technologies provide externally, gently and non-destructively, cost-effective and scalable solutions to assess crop quality and health, detect abiotic and biotic stress factors and optimise orchard management practices. The objective of this paper is to provide a comprehensive review of recent advancements in the field of remote sensing techniques, machine learning, deep learning, unmanned aerial vehicles, and intelligent systems in orchard management. This review aims to offer a comprehensive overview of the application of these techniques in orchards and to propose relevant recommendations. Firstly, the paper sets out the principles of remote sensing using various sensors and platforms for the purpose of creating a data pool through the use of broad spectrum, hyperspectral and thermal imaging technologies. The paper then examines in detail the studies on these issues and the resulting detailed information obtained about fruit trees and the environmental environments in which they are located. The subsequent discourse delves into the applications of remote sensing in the context of monitoring fundamental biophysical parameters, including vegetation indices, canopy structure, and water stress. The text does not address the subject of the development of decision-making processes for operational requirements in orchard management, with the objective of ensuring accuracy and timeliness. Furthermore, the text goes on to explore the ways in which diseases can be detected before they reach the damage threshold, the estimated yield, and the practical benefits of remote sensing in precision agriculture applications in orchards, with the aid of illustrative examples. The challenges that may be encountered, such as the processing of data, the integration of data sources, and the scalability of the system, have been thoroughly examined in conjunction with the research and technological advancements. In addition, the study encompassed the following: The utilisation of digital agriculture, machine learning, remote sensing and smart system techniques has been demonstrated to be a highly effective means of increasing fruit production. It is hypothesised that the implementation of such novel approaches in the domain of fruit orchard management by researchers and decision-makers will engender contributions to the enhancement of fruit yield and the sustainability of fruit production.

Keyword: *smart systems, remote sensing, plant health, sustainability, innovative approach*

Introduction

The use of smart systems is increasingly expanding from industry and manufacturing to agriculture and even food production. Their use in agricultural production, in particular, has become a necessity for the agricultural sector to be more efficient, sustainable, and smart in the face of challenges such as increasing global food demand, climate change, and resource scarcity. In this context, machine learning algorithms from smart systems make significant contributions in areas such as soil analysis, crop yield prediction, disease detection, and resource management. Machine learning methods are particularly widely used in agriculture. Various ML algorithms such as decision trees, random forests, support vector machines (SVM), and artificial neural networks have begun to be used extensively in this system. Clustering techniques are used, especially in crop classification and soil type analysis. It has been noted that models such as CNN are effective in tasks such as image processing and object recognition. The main areas where machine learning techniques are applied in agriculture are as follows: Productivity estimation, where the amount of product is estimated using historical data and environmental factors. Disease and pest detection: Leaf diseases and pests can be detected at an early stage using image processing. Soil and water management: Parameters such as soil moisture and pH level are analyzed using sensor data to optimize irrigation and fertilization. Autonomous systems, drones, and robots are guided by ML algorithms to automate planting, harvesting, and spraying operations. However, there are also some obstacles to the widespread adoption of ML applications in agriculture. These include data scarcity and poor data quality, high hardware costs, farmers' adaptation process to technology, and model generalization issues (different results in different regions). It is anticipated that more integrated systems (IoT + ML + cloud computing) will become widespread in the future and that decision support systems will provide farmers with real-time recommendations. Furthermore, it is considered necessary to develop open data platforms and create customized models at the local level (Mohyuddin, et al., 2024). The transformation experienced by the agricultural sector through machine learning (ML) technologies and efforts to integrate Information and Communication Technologies (ICT) into traditional agricultural practices are progressing at a dizzying pace. In the current environment of "data tsunami," a paradigm shift is observed in the fields of smart agriculture and precision farming. Machine learning algorithms can analyze past and real-time environmental data and soil conditions to predict the most suitable crop selection for maximum yield, detect diseases early, and optimize irrigation processes. This facilitates farmers' ability to make informed decisions. Precision agriculture, on the other hand, ensures high accuracy in planting, harvesting, and crop monitoring through autonomous vehicles and drones. The use of these technologies leads to significant increases in resource efficiency. Machine learning optimizes energy consumption, manages fertilizer use, and promotes climate-resilient practices (Mohyuddin et al., 2024). Digital agriculture (or smart agriculture) has entered a transformation process that goes beyond traditional methods and focuses on technology. This transformation comprehensively addresses the role played by agricultural robots and research and development (R&D) activities in this field. The evolution of robots in agriculture initially involved machines that performed only mechanical tasks. However, today these systems have been transformed into systems equipped with sensors, capable of detecting environmental data, making decisions using artificial intelligence and machine learning, and moving autonomously. This evolution has enabled robots to be used not only as physical labor but also as decision support systems. Application areas and robot types include planting and sowing robots that precisely place seeds and can adjust depth and spacing according to soil structure. They operate flawlessly with GPS-guided navigation, while harvesting robots are used specifically for gathering delicate products such as fruits and vegetables. It determines ripeness through image processing. It enables hygienic harvesting without human contact. Spraying and fertilizing robots can perform targeted spraying based on plant health. This allows farmers to reduce chemical use, offering an environmentally friendly approach. Weed control identifies weeds through image processing and artificial intelligence, enabling targeted intervention to target only unwanted plants. Soil and plant analysis sensors collect data such as soil moisture, temperature, and pH, and use this data to optimize irrigation and fertilization decisions. The core technologies used include image processing for plant health, maturity, and weed detection. Machine learning is critical for robots to perceive their environment and make decisions. GPS/GNSS is used for precise positioning of robots in the field, enabling sensors to continuously monitor soil and environmental conditions. Cloud computing enables the analysis of collected data and facilitates remote management. Despite providing all these conveniences, the most common challenge is high cost. The production and maintenance costs of robots are still quite high. Variable field conditions, such as mud, slopes, and rocky terrain, can negatively affect robot performance. Battery life and energy consumption are still factors in energy efficiency. Farmers' adaptation to these technologies is another issue. As is well known, training and support are required for users who are not accustomed to technology. In summary, it is predicted that in the near future, robots will be able to communicate with each other, make real-time decisions, and serve as decision support systems for farmers. Furthermore, in this scenario, the integration of artificial intelligence and robotic systems has the potential to increase agricultural productivity while reducing environmental impacts (Shamshiri, et al., 2018). A study conducted in Thailand evaluated the effects of smart farming technologies in digital agriculture projects implemented in the Chanthaburi region of Thailand. Highlighting the fundamental challenges facing agriculture today, factors such as the growing world population, declining agricultural land, climate change, and the reduction in the agricultural workforce have rendered traditional farming methods inadequate. In this context, smart agriculture technologies have great potential in terms of increasing productivity, optimizing resource use, and ensuring sustainability. This study examines the basic components of smart agriculture in detail. First, thanks to the Internet of Things (IoT) technology, sensors placed in fields collect environmental data such as soil moisture, temperature, and light intensity in real time, and this data is used to automate processes such as irrigation. This ensures both water conservation and plant health. Unmanned aerial vehicles (drones) enable aerial monitoring of large agricultural areas, providing high-resolution images for plant growth, disease, and pest detection, thereby enabling farmers to intervene early. The collected data is processed using artificial intelligence and big data analytics, enabling more accurate decisions to be made regarding product yield estimation, disease diagnosis, and fertilization planning. Machine learning algorithms learn from past data to predict future possibilities and provide recommendations to farmers. All these technologies are managed in an integrated manner through digital platforms called Smart Agricultural Management Systems (SAMs). These systems provide farmers with real-time information about the status of their fields and facilitate decision-making processes. Furthermore, this study examines the example of the Data Center (DCC) established in Thailand's Chanthaburi region, suggesting that regional agricultural data can be collected and analyzed to develop solutions tailored to local conditions. This center is reported to play a significant role in creating digital agriculture strategies specific to the region. The benefits provided by smart agriculture technologies include increased productivity, sustainable production, real-time intervention capabilities, and traceability of production processes. However, this study also points out that there are some obstacles to the widespread adoption of these technologies. High initial costs, farmers' lack of technical knowledge, data security issues, and inadequate infrastructure in rural areas are among these obstacles. In summary, this study paints a promising picture for the future of smart agriculture. It is stated that the widespread adoption of agricultural platforms integrated with full automation, artificial intelligence-supported decision systems, and regional data centers is expected. These developments are anticipated to make the agricultural sector more efficient, sustainable, and resilient (Thongnim, et al., 2024; El-Ansary., 2025). Work is rapidly progressing on new orchard management systems that combine artificial intelligence (AI)-powered robots and Internet of Things (IoT) sensors. These systems use an algorithm called reinforcement learning (RL) to enable robots to adapt to the garden environment and perform tasks more efficiently. The system provides robots with real-time information using IoT data, helping them make more accurate decisions in tasks such as pruning, harvesting, and plant health monitoring. The tests conducted have demonstrated that this AI-focused system operates with fewer resources and higher efficiency compared to traditional methods. Consequently, the adoption and widespread use of these technologies hold significant potential for more sustainable and efficient agricultural practices (Ranganathan et al., 2025).

Use of New Systems Such As Smart, Digital, Remote-Controlled, Unmanned Aerial Vehicles and Machine Learning In Orchard Management

Today, the integration of digital technologies is becoming increasingly important in order to increase agricultural production efficiency, optimize resource use, and ensure environmental sustainability. In this context, advanced technologies such as smart systems (smart, digital, remote-controlled, unmanned aerial vehicles, and machine learning) in orchard management are replacing traditional methods, enabling more precise, faster, and data-driven decision-making processes. In this regard, Bharad and Khanpara (2024) conducted a study in which they integrated robotic technologies into agriculture, initiating a fundamental transformation in this sector and offering innovative solutions to long-standing problems such as labor shortages, rising production costs, and the need for increased productivity. Among these developments, agricultural fruit harvesting robots stand out as a significant innovation with the potential to fundamentally change traditional agricultural practices. This study provides a comprehensive overview of autonomous fruit harvesting robots and examines their impact on agricultural applications. The Agricultural Fruit Harvesting Robot (AFHR) is considered a significant milestone in modern agriculture. These robots are equipped with advanced sensors, actuators, and machine learning algorithms. Thanks to this technology, they can identify ripe fruit, gently grasp it, and efficiently harvest it from trees. The design of the AFHR has been developed to be flexible and versatile, capable of adapting to different fruit types, shapes, sizes, and garden layouts. This allows it to find a wide range of applications in various agricultural environments. Fundamental technological components such as computer vision systems and machine learning algorithms enable the robot to distinguish fruit ripeness levels. This contributes to optimizing harvest timing, thereby increasing yield and reducing waste. Thanks to autonomous navigation systems, robots can move efficiently in orchards, avoid obstacles, and work without damaging plants. Additionally, soft grippers integrated into robotic arms ensure that fruits are handled gently, minimizing the risk of bruising and damage. Autonomous fruit harvesting robots offer a promising solution to address labor shortages, increase operational efficiency, and improve the sustainability of fruit production systems. Continuous advances in technology will further enhance the capabilities of these robots and encourage their widespread adoption in agricultural applications. As a result, AFHR is at the forefront of agricultural innovation and stands out as a technology poised to redefine the future of fruit harvesting. These robots will play a significant role in ensuring higher productivity, sustainability, and profitability in the agricultural sector.

In recent years, for example, work has continued on using an intelligent management system for apple orchards. By transferring each tree, the soil, and the environmental conditions of the apple orchard into a digital environment, a “digital twin” that is a complete copy of the orchard is created. Thanks to this digital twin, the condition of the garden can be monitored in real time using data collected via sensors and cameras (e.g., soil moisture levels, air temperature, tree health). This system analyzes the data it collects to assist farmers in the following areas: It optimizes irrigation by determining how much water each area needs, thereby preventing water waste; it detects potential disease symptoms in trees at an early stage, enabling rapid intervention; it predicts how much yield can be obtained at harvest time; and it reduces costs by ensuring that processes such as fertilization and spraying are carried out at the right time and in the right amount (Schneider Castro, 2025).

As is well known, the agricultural sector must adapt to challenges such as global temperature changes, environmental degradation, declining agricultural labor force, population growth, and changing dietary habits. Various methods such as plant breeding, genetic engineering, and precision agriculture are being applied to increase agricultural productivity. In recent years, with the rapid development of scientific and technological innovations such as unmanned aerial vehicles (drones), smart sensors, robotic systems, and remote sensing technologies; revolutionary methods have emerged in many areas such as real-time product modeling, high-throughput phenotyping, weather forecasting, yield prediction, fertilizer application, disease detection, market tracking, and environmental applications. These methods are critical in terms of product development, yield, and quality. Furthermore, big data analytics, advanced data processing techniques, falling technology costs, faster internet connections, increasing digital connectivity, and advances in processing power are among the key elements supporting the digitalization process in agriculture. This digital transformation contributes to commercial agriculture achieving its goals of smart farming, resilience, productivity, and sustainability. These technologies enable the effective monitoring of plants, soil, and environmental conditions across large agricultural areas, providing farmers with the ability to make precise management decisions that maximize productivity and minimize environmental impacts. However, despite the significant potential offered by smart farming, there are also some challenges, such as high implementation costs, data security concerns, and a lack of digital literacy among farmers. As a result, the agricultural sector is undergoing a rapid transition from traditional methods to digital applications. This transformation offers advantages such as the capacity to produce solutions on a global scale, the efficient use of resources, and the reduction of input costs; it also increases the welfare of farmers and contributes to economic growth. This perspective emphasizes the role of technology in solving critical issues such as environmental degradation and threatened biodiversity, drawing attention to the opportunities offered by digitalization. Future developments are expected to focus on areas such as data encryption, digital literacy, and specific economic policies (Balyan, 2024).

A study examining the integration of digital technologies with precision farming applications in fruit production comprehensively investigates the critical role these technologies play in achieving modern agriculture's goals of productivity, quality, and sustainability. The limitations of traditional methods in agricultural production, particularly issues such as labor shortages, resource waste, and environmental impacts, have increased the importance of digital solutions. The development of precision agriculture applications, especially in fruit production, has been evaluated through the technological tools and methods used in this field. In this context, the integration of digital tools such as remote sensing systems, geographic information systems (GIS), sensor-based monitoring technologies, artificial intelligence-supported decision systems, robotic harvesting machines, and data analytics into production processes has been addressed. The main contributions of these technologies to fruit production can be summarized as follows. Thanks to increased productivity, real-time monitoring of plant growth, soil conditions, and environmental factors, production processes can be managed more precisely and efficiently. Quality control; thanks to image processing and sensor technologies, quality parameters such as fruit ripeness, color, and size can be automatically evaluated, which improves classification and marketing processes. In terms of resource optimization, costs are reduced and environmental impacts are minimized by ensuring that inputs such as water, fertilizer, and pesticides are applied only in the required amounts and at the right time. The data collected on traceability and decision support enables every stage of the production process to be digitally tracked and recorded, offering significant advantages in terms of both food safety and producer decisions. It also addresses some of the challenges to the widespread adoption of these technologies. In particular, high investment costs, lack of digital literacy, inadequate infrastructure, and data security issues are the main factors limiting the adoption of technology in rural areas. Briefly, this study emphasizes that the integration of digital technologies with precision agriculture practices in fruit production is one of the fundamental dynamics that will shape the future of agricultural production. By making these technologies more accessible, user-friendly, and economical, it will be possible to achieve higher yields, quality, and sustainability in fruit production (Murthy and Gutam 2024)

Schneider Castro et al. (2025) conducted a thesis study at the Politecnico University in Italy, researching the design, development, and implementation of a monitoring system for an apple orchard. The system used in this study is reported to provide useful information about apples, such as their health status and location, by creating an integrated digital twin (DT) of the orchard in question. The work carried out within the scope of the thesis is a continuation of a project previously initiated by the Department of Environmental, Land, and Infrastructure Engineering (DIATI) and the Department of Mechanical and Aerospace Engineering (DIMEAS) at the Politecnico di Torino.Data collection was performed using multispectral cameras and a stereo camera mounted on the Agri.Q agricultural unmanned ground vehicle (UGV), developed by DIMEAS and controlled remotely. Multispectral cameras have determined the health status of each tree by measuring the light reflected from the leaves during photosynthesis. Meanwhile, a point cloud was extracted from the SVO file recorded by the stereo camera; apples were detected and located using artificial intelligence (AI) and neural networks with the integrated Inertial Measurement Unit (IMU). Additionally, a LiDAR scanner was used to obtain the geographic reference point cloud of the orchard. Within the scope of the project, the necessary support structure for mounting the sensors on the UGV was designed; camera placement and orientation were considered to ensure that the apple trees could be framed as desired and that the images had an appropriate overlap ratio. Following the data collection process, point clouds obtained from various camera and sensor outputs were combined to form a single integrated point cloud. As a result, the system developed within the scope of this thesis enabled the monitoring of apple orchards through their digital twin, and the health status and location of apples were successfully determined. Multispectral and stereo cameras, LiDAR scanners, and AI-supported analysis methods have enabled a significant step toward digitalization in agricultural production. The results obtained demonstrate the effectiveness of digital twin technology in precision farming applications and lay the foundation for future similar studies.

Melnychenko et al. (2024) conducted a study on the development of an intelligent system that integrates multi-unmanned aerial vehicle (UAV) imaging systems with deep learning techniques to make fruit detection and monitoring processes in agricultural production more efficient and accurate. This system, developed by Melnychenko and colleagues, combines multiple UAV images obtained from different angles and heights to provide a solution that ensures high accuracy in fruit detection and positioning. Deep learning algorithms, particularly convolutional neural networks (CNN), have been effectively used in the automatic recognition and classification of fruits. In this context, the study in question responds to the need for fast, automatic, and accurate data collection over large areas, overcoming the limitations of traditional fruit detection methods. The system makes a significant contribution to solving the problem of time-consuming and costly manual observation and data collection processes, particularly in large-scale agricultural areas. In the associated thesis work conducted in relation to this article, a similar digital twin approach was adopted; however, this time a ground-based agricultural unmanned ground vehicle (UGV) was used to develop a monitoring system specifically for apple orchards. Tree health and fruit locations have been successfully detected using multispectral and stereo cameras, LiDAR scanners, and artificial intelligence-supported analysis methods. Both studies serve as important examples in terms of digitalization in agriculture and the widespread adoption of precision farming practices. Consequently, these studies demonstrate how innovative technologies developed to increase agricultural production efficiency, optimize resource use, and reduce dependence on human intervention can be effectively implemented through both airborne and ground-based platforms.

As is well known, almond cultivation has become an important agricultural activity worldwide in countries with suitable ecological conditions, due to increasing demand and high nutritional value. In this context, this systematic review study conducted by Guimarães et al. (2024) comprehensively informs about current trends, research gaps, and future potential applications regarding the use of remote sensing technologies in almond orchards. This study analyzed 82 scientific articles published between 2010 and 2023 in accordance with the PRISMA protocol and identified the main areas of application of remote sensing in almond farming. According to the findings, water management is the area with the highest concentration of remote sensing applications, addressed in 34 studies. This was followed by applications such as image classification (14 studies), tree segmentation and parameter extraction, plant health monitoring, and disease detection. The countries contributing most to almond production worldwide are the United States, Australia, and Spain, respectively. Given that these countries also hold leading global almond production positions, this study examines and evaluates active research in all areas of application in these countries. This study systematically presents the current status of remote sensing technologies in almond orchards, identifies gaps in knowledge, and offers guidance for future research. It also makes significant contributions to the development of sustainable agricultural practices and the dissemination of precision agriculture technologies. The recommendations presented in this study can be summarized as follows: While research on water management is generally quite intensive, there is a need for more research in areas such as disease detection, tree segmentation, yield estimation, and nutrient status monitoring. Advanced technologies, such as hyperspectral imaging and thermal sensors, have not been sufficiently researched in almond farming. To obtain more accurate and comprehensive results, data from different sensors (e.g., RGB, multispectral, LiDAR) to obtain more accurate and comprehensive results, the more widespread and systematic use of machine learning and deep learning algorithms, and the diversification of remote sensing platforms, for example, developing more sustainable solutions by using satellite images, fixed camera systems, and ground-based sensors together, without relying solely on UAV-based data. In addition, it is recommended that, in order to increase geographical diversity, while a large portion of research is concentrated in leading producer countries such as the USA, Australia, and Spain, similar studies should also be conducted in other producer countries. This is important for more accurately understanding the effects of climatic and geographical differences, and it is suggested that application-oriented studies should be increased. In summary, it is emphasized that academic studies should interact more with agricultural practitioners and produce practical solutions. Lachgar et al. (2023) conducted a review study that comprehensively examined current trends, technological developments, and application areas related to the use of unmanned aerial vehicles (UAVs) in smart agriculture applications. According to this study, with the acceleration of digitalization in the agricultural sector, UAVs have become an important tool in data collection, analysis, and decision support processes. It is emphasized that UAVs are used particularly in areas such as crop health monitoring, disease and pest detection, irrigation management, yield estimation, mapping, and fertilizer optimization. Additionally, it is stated that these systems offer faster, more economical, and more precise solutions compared to traditional methods, thanks to their capabilities such as high-resolution imaging, real-time data transmission, and AI-supported analysis. The article compares the advantages and limitations of different types of UAVs (fixed-wing, rotary-wing, etc.); it also evaluates the role of sensor technologies (multispectral, thermal, RGB) in agricultural applications and states that UAV-based systems have the potential to increase efficiency in agricultural production, but there are still issues to be resolved regarding data processing infrastructure, regulations, user training, and economic accessibility.

Zhang et al. (2021) conducted a comprehensive review study that systematically examined perception and analysis approaches for the use of small unmanned aerial vehicles (UAVs) in orchard management. In recent years, the miniaturization of sensors and the widespread adoption of UAV technologies in agriculture have enabled the development of precision farming applications, particularly in orchards. However, one of the biggest obstacles to the widespread adoption of these technologies is the lack of a standardized application workflow. Orchards are complex systems that require tree-based management throughout the entire growth cycle, from flowering to fruit ripening and harvest. Therefore, technologies capable of collecting data at the local and individual tree level are needed. In this context, UAVs offer significant potential with their high-resolution imaging and rapid data collection capabilities. UAVs offer significant advantages in terms of efficiency, accuracy, and time savings in

orchards. There is diversity in data processing techniques; however, this diversity makes standardization difficult in practice. Although the performance of new technologies (e.g., artificial intelligence-supported analyses) is promising, these systems need to be tested and optimized under field conditions. Conclusions and Recommendations: Standard workflows need to be developed to promote the widespread use of UAV-based systems in orchard management. Integrating sensor data and developing automated decision support systems will increase application success. Future research should focus on issues such as application accuracy, economic feasibility, and user-friendly interfaces.
Sarkar (2025), in the book chapter titled "Automation and the Future of Food," discusses the integration of machine learning and remote sensing technologies for the early diagnosis of diseases in orchards. He states that diseases in agricultural production pose serious threats to product quality and yield, while traditional diagnostic methods are time-consuming, require expertise, and are costly processes. He defines a machine learning workflow that includes steps such as collecting leaf images, preprocessing, segmentation, feature extraction, and classification, and demonstrates how this process can be supported by remote sensing data. Models trained with different sensor data such as RGB, multispectral, and thermal images have been highlighted for their ability to detect diseases with high accuracy in the early stages. However, challenges such as data quality, labeling process, and model generalization have also been noted. As a result, the integration of these technologies offers a powerful solution for early intervention and precision farming applications in orchards; it also emphasizes the need to make them more accessible in the future through real-time systems, mobile applications, and cloud-based analysis platforms.
Zheng et al. (2021) conducted a review study examining the integration of remote sensing and machine learning in agricultural phenotyping and management processes. They emphasized that the rapid and accurate measurement of plant characteristics, particularly in strawberry farming, is a critical need for both plant breeding and agricultural management. In this context, data obtained using various sensors such as high-resolution RGB, multispectral, hyperspectral, chlorophyll fluorescence, and LiDAR are processed using machine learning and computer vision techniques to evaluate many agricultural characteristics, such as enabling the assessment of numerous agricultural characteristics such as fruit/flower detection, ripeness and quality analysis, leaf and stem characteristics, water stress status, and disease and pest detection.
Sharma and Shivandu (2024), in their review study, examined how the integration of artificial intelligence (AI) and Internet of Things (IoT) technologies has transformed plant monitoring and management in precision agriculture applications. They reported that innovative methods such as high-throughput phenotyping, remote sensing, and agricultural robots (AgroBots) have significantly reduced labor costs and environmental impacts by automating processes such as harvesting, sorting, and weed detection. Data on plant characteristics is collected through remote sensing, spectral imaging, and robotic systems; this data supports decision-making processes such as fertilization, irrigation, and pest management. DGPS and remote sensing systems are reported to provide accurate and real-time information about soil conditions and plant health. Advanced image segmentation techniques are said to ensure high accuracy in plant and fruit detection despite variable light conditions and complex backgrounds. Examples such as the PACMAN SCRI project used in apple production and the PANTHEON SCADA system applied in hazelnut orchards demonstrate the transformative power of AI and IoT in agricultural applications. The integration of upcoming 5G and future 6G mobile networks is noted to potentially support the widespread adoption of smart farming applications by resolving connectivity issues. However, research gaps remain in areas such as the integration of different data sets, scalability for small and medium-sized farms, and the development of real-time decision support systems. It is recommended that robust AI models and IoT devices suitable for different agricultural conditions be developed, user-friendly interfaces be designed, and measures be taken regarding data privacy and security. It is reported that addressing these shortcomings will significantly contribute to the more effective and sustainable use of AI and IoT in agriculture.

Results and Discussion

This study comprehensively examines the opportunities offered by digital agriculture technologies in orchard management, contributing to making production processes more efficient, sustainable, and intelligent. Thanks to innovative approaches such as machine learning, remote sensing, unmanned vehicles, and the Internet of Things, fundamental agricultural activities such as plant health monitoring, early diagnosis of diseases, yield estimation, irrigation, and fertilization can be carried out in a more precise and data-driven manner. These technologies reduce labor costs, minimize environmental impacts, and accelerate decision-making processes. However, there are also some technical and application-based challenges in this transformation process. In particular, issues such as access to these systems for small and medium-sized enterprises, data security, infrastructure deficiencies, and user training are among the areas awaiting solutions. Therefore, future efforts should aim to make digital agriculture systems more accessible, scalable, and user-friendly. Furthermore, transforming data obtained through the integration of different technologies into meaningful and real-time decision support systems will increase efficiency in agricultural production. In this context, it is recommended that training programs, open-source software, and mobile applications be developed to facilitate farmers' adaptation to technology. The spread of digital agriculture will directly and positively impact not only production efficiency but also food safety and environmental sustainability.

Declaration of Competing Interest
The authors report no declarations of interest.

References

Balyan, S., Jangir, H., Tripathi, S. N., Tripathi, A., Jhang, T., and Pandey, P. (2024). Seeding a sustainable future: Navigating the digital horizon of smart agriculture. Sustainability, 16(2), 475. https://doi.org/10.3390/su16020475

Bharad, N. B., and Khanpara, B. M. (2024). Agricultural fruit harvesting robot: An overview of digital agriculture. Plant Arch, 24, 154-160. https://doi.org/10.51470/PLANTARCHIVES.2024.v24.SP-GABELS.023

El-Ansary, D. O. (2025). Smart Farming and Orchard Management: Insights and Innovations. Current Food Science and Technology Reports, 3(1), 10. https://doi.org/10.1007/s43555-025-00055-x

Guimarães, N., Sousa, J. J., Pádua, L., Bento, A., & Couto, P. (2024). Remote sensing applications in almond orchards: A comprehensive systematic review of current insights, research gaps, and future prospects. Applied Sciences, 14(5), 1749. https://doi.org/10.3390/app14051749

Lachgar, M., Hrimech, H., and Kartit, A. (2023). Unmanned aerial vehicle-based applications in smart farming: A systematic review. International Journal of Advanced Computer Science and Applications, 14(6).

Melnychenko, O., Scislo, L., Savenko, O., Sachenko, A., and Radiuk, P. (2024). Intelligent integrated system for fruit detection using multi-UAV imaging and deep learning. Sensors, 24(6), 1913. https://doi.org/10.3390/s24061913

Mohyuddin, G., Khan, M. A., Haseeb, A., Mahpara, S., Waseem, M., and Saleh, A. M. (2024). Evaluation of machine learning approaches for precision farming in smart agriculture system: a comprehensive review. IEEE access, 12, 60155-60184.

Murthy, B. N. S., and Gutam, S. R. I. D. H. A. R. (2024). Advances in Precision Production of Fruits through the Use of Digital Technologies.

Ranganathan, C. S., Raman, R., Divekar, B. R., Jeevitha, N., Thilagavathy, A., and KP, M. (2025). AI-Driven Robotics and IoT for Advanced Precision Orchard Management. In 2025 11th International Conference on Communication and Signal Processing (ICCSP) (pp. 205-210). IEEE.

Sarkar, T. (2025). Integrating Machine Learning and Remote Sensing for Early Disease Detection in Orchard Crops. Frontiers in Agriculture: AI, Automation and the future of food, 1, Page 142.

Schneider Castro, M. N. (2025). Monitoring system of an apple orchard Design, development and implementation of a monitoring system for an apple orchard, through the creation of an integral digital twin (Doctoral dissertation, Politecnico di Torino).

Sharma, K., and Shivandu, S. K. (2024). Integrating artificial intelligence and Internet of Things (IoT) for enhanced crop monitoring and management in precision agriculture. Sensors International, 5, 100292. https://doi.org/10.1016/j.sintl.2024.100292

Shamshiri, R.R., Weltzien, C., Hameed, I. A., J Yule, I., E Grift, T., Balasundram, S. K., and Chowdhary, G. (2018). Research and development in agricultural robotics: A perspective of digital farming. https://doi.org/10.25165/j.ijabe.20181104.4278

Thongnim, P., Yuvanatemiya, V., Srinil, P. (2024). Smart Agriculture: Transforming Agriculture with Technology. In: Hassan, F., Sunar, N., Mohd Basri, M.A., Mahmud, M.S.A., Ishak, M.H.I., Mohamed Ali, M.S. (eds) Methods and Applications for Modeling and Simulation of Complex Systems. AsiaSim 2023.

Communications in Computer and Information Science, vol 1911. Springer, Singapore. (pp. 362-376). https://doi.org/10.1007/978-981-99-7240-1_29

Zhang, C., Valente, J., Kooistra, L., Guo, L., and Wang, W. (2021). Orchard management with small unmanned aerial vehicles: A survey of sensing and analysis approaches. Precision agriculture, 22(6), 2007-2052. https://doi.org/10.1007/s11119-021-09813-y

Zheng, C., Abd-Elrahman, A., and Whitaker, V. (2021). Remote sensing and machine learning in crop phenotyping and management, with an emphasis on applications in strawberry farming. Remote Sensing, 13(3), 531. https://doi.org/10.3390/rs13030531

Designing and Creating a New Software Programme for Management in Dairy Farms

Nada N. A. M. Hassanine[1] , Ahmed A. Saleh[1,2], Mayar Al-Mahrangi[2], Youssef Abdel-Gawad[2], Yara Abdel-Radi[2], Ahmed Zeytoun[2], Alaa Al-Masry[2], Osama Abdel-Gawad[2], Hosameldeen Mohamed Husien[1], Mengzhi Wang[1, *]

[1] College of Animal Science and Technology, Yangzhou University, Yangzhou, 225009, China.
[2]Animal and Fish Production Department, Faculty of Agriculture (*Al-Shatby*), Alexandria University, Alexandria City, 11865, Egypt.

[*]**Corresponding Author:** mengzhiwangyz@126.com

Abstract

The current work presents the findings regarding creating a new software programme for production and reproduction management in dairy farms. Also, it can be used in the accounting department and the genetic breeding of bovine herds. Advanced programmes such as; Visual Basic and Data Base Access were used in the present work to innovate and design a new software programme named Farm-Key for dairy farm management to keep pace with new high technology in the animal production sector. Eight simulation models were developed to plan and manage several dairy farm practices and facilities, such as; animals, nutrition, reproduction, production, vaccination, marketing, management and map. A decision tree was developed for each simulation model, and then the simulation models were integrated into the relevant decision trees. The new application programme is expected to provide fast development, management and cost-effectiveness for management in dairy farms with perfect security. Therefore, the Farm-Key programme could be a tool that allows users to interact with a database, designed for large amounts of information, whose management requires a rigid structure and rational access and processing.

Keywords: *Software programme, Dairy farm, livestock farming, Simulation model*

Introduction

Superior germplasm, better nutrition strategies, health care facilities and improved dairy husbandry practices have boosted milk yield and its quality at a rapid rate (Omer 2022). Per cow, productivity has risen sharply with a considerable increase in the population of dairy animals. The recent era has witnessed the extension of large dairy farms worldwide, especially smart farms which include high-technology constructions, advanced devices and tools, and Apps/ software programmes (Brito *et al*. 2021; Singh *et al*. 2021). On the other hand, the demand for high-quality and increased quantity of milk is of prime concern for all dairy farms. With an increase in the size of animals on a farm, the labour required also rises. The availability of skilled labour at a low wage rate is becoming difficult (Grasseni 2007; Mamane 2022). In the last couple of decades, the cost of management has been reduced to a reasonable level by increasing advanced devices and tools that are managed by special software programmes. The economic availability of these programmes, artificial intelligence, and improved data statistics combined with expert suggestions have created a revolution in livestock farming. Advanced software programmes alongside engineered devices have become alternatives to reduce high labour costs (Barile *et al*. 2022; Santos *et al*. 2022; Singh *et al*. 2022).

In the past two decades, software programmes have been developed to manage dairy cow breeding. There has been an increase in the demand and use of such instruments in recent years. Various products have appeared on the market today, with each of them having its characteristics and properties, able to satisfy breeders' various demands and necessities for data management (Maciuc *et al*. 2015; Kang *et al*. 2021; Tassinari *et al*. 2021).

In the middle of the 80s, the first breeding management software was introduced for dairy cows. With the development of new technologies, breeding practices, and assistance plans, animal husbandry is experiencing new exigencies and tendencies in data management. A variety of applications can be found in nutrition system management, reproduction planning, as well as gynaecological and veterinary health care, also, morphological and genetic evaluation of animals (linear system and genetic indexes) concerning the selection and improvement of breeding animals (Grasseni 2005; Maciuc *et al.* 2015). In this context, software programmes represent a new and efficient instrument for providing rational and opportune management of different aspects, which are involved in cattle breeding in particular and for populations in general. In the coming years, the farmers' demands will increase and the already existing software will be improved and progressively updated and will also be accompanied by more advanced new software. Some of these are specially developed for technological processes management (feeding, breeding, reproduction, etc.), and others are specialised at a higher level for using new technological processes such as quantitative and qualitative automatic dosage of production, pedometers, etc.(Maciuc *et al.* 2015; Magnusson *et al*. 2022).

Worth mentioning, the traditional management, software products are more and more regarded as flexible instruments for analysis and programming into a technological flow. In other words, these are required functions that allow carrying on a more or less complex analysis and personalized breeding performances to discover the critical points (Maciuc *et al.* 2015; Kang *et al.* 2021).

An examination of the breeders' problems is very important for efficient usage of this instrument and to avoid the possibility, which in many cases has become real, of sub-usage or misuse of software programmes. So, it is necessary to plan the usage of the software programmes, in other words, to establish which departments of a farm will be automated. For the same purpose, there will take place the identification of the data to be tracked and also the human resources (users) respective to technological resources (software-related peripheral units) which will be used. These are some aspects strongly connected between them, since the decision to use a certain technology was made, and means to assure an organisation form and the type of management procedures could determine the possibility of exploitation or not of some certain opportunities provided by software programmes (Samer 2010; Tummers *et al*. 2021).

This work focuses on the latest knowledge and emerging developments in animal welfare-focused software programmes to keep up activities and activity-based welfare assessments like milk production and quality, oestrus, artificial insemination (AI), diseases and others. The use of advanced software programmes and data technologies with expert-based solutions is anticipated to bring out a substantial improvement in existing dairy farming practices.

This work aimed to create a new software programme namely "Farm-Key" for management in dairy farms using Visual Basic. To plan and manage several dairy farm practices and facilities, such as; animals, nutrition, reproduction, production, vaccination, marketing, management and map/view.

Material and methods

Problem and objectives of creating a new software programme for management in dairy farms

The planning and design of dairy farm practices and facilities is a complicated process involving numerous procedures that require time and effort; additionally, mistakes may occur. To accelerate analyses and improve decision-making, computer tools need to be developed that can pre-process data to produce value-added information. A software programme is developed to plan and manage dairy farm facilities, calculate the required number of materials, implement technologies, and calculate costs.

Research Methods

Through Visual Basic and Data Base Access, we created a new software programme/Farm-Key to achieve efficient data management regarding the nutrition, vaccination, milk production and fertility performance, of a farm and also the selection and works carried out based on the official control of the performances but also on directed reproduction, especially through AI. Also, we tried to ensure flexibility for animals' recording with all the upgraded data, with possibilities of adding new data for the same animal, introducing new breeds or lines and identifying animals as easily as possible in the moment of data extraction or creating new databases used for different statistical interpretations, creating origin certificates, data files (savings, security, etc.).

For this purpose, a database management system, Visual Basic and DB Access were used to create the Farm-Key programme and to ensure the independence between data logic relations and their minimum redundancy. This system allows rapid development and provides a low price for data application programmes exploring a complex structure, also providing fast access to dates and strong security of them. In other words, this programme allows the users to interact with a database designed usually for great amounts of dates at its management level to impose not only a rigorous structure but also easy access and rational processing.

Visual Basic can be mainly used by two categories of users: designers and software developers who write Visual Basic applications, and final users who can easily administrate the dates using the user interface. To run the application, it is necessary to have a computer with Windows 8, 8.1, 10 or 11. Currently, the software cannot run on smartphones.

Key benefits of creating a new software programme for management in dairy farms

The users can get several benefits by using the Farm-key programme, such as; **1)** Easy access to your whole herd, **2)** View comprehensive individual cow records, **3)** Keep milk production on target with accurate quota predictions, **4)** Import milk records, **5)** Milk production and bulk tank analysis reports with forecasting, **6)** Notify movements in the dairy farm, **7)** Eliminate data entry duplication with links to many parlour/heat detection systems, **8)** Access your cow records outside at any time on a tablet, **9)** Prepare action lists for your vet to assist with pre-visit planning, **10)** Record and report for dairy herd health planning, **11)** Records and analyses all cases and treatments for mastitis and lameness, **12)** Print off web format practices record, **13)** Calculate the nutrition level for each group of production, **14)** Current action lists instantly tell you who's due to calve, be served, dried off, ... etc, **15)** Check bloodlines don't cross over with the relations report, **16)** All births, deaths, purchases and sales automatically update the statutory movements book, **17)** An easy-to-read herd fertility chart helps ensure you do not miss any cows getting back into calf, **18)** Keep full young-stock records for both dairy heifers and beef calves, **19)** Analyse your Herd Fertility to monitor submission/ conception rates, **20)** get the pedigree registrations, **21)** It is very straightforward to operate and is ideal for herd managers looking to move up from manual records to computerisation, and **22)** New events can be quickly entered into the program, instantly updating a range of reports.

Results

The Farm-Key programme, was designed after the name of the farm of the Faculty of Agriculture, Alexandria University, Egypt **(Figure 1)**. Eight simulation models were developed to plan and manage several dairy farm practices and facilities; animals, nutrition, reproduction, production, vaccination, marketing, management and map/view **(Figure 2)**. A decision tree was then built for each simulation model, and the simulation models were then integrated into the relevant decision trees. The Visual Basic programming language was also used to develop a programme through simulation models and decision trees. The new application software is expected to provide rapid development, management and cost-effectiveness of management in dairy farms with optimal security. Therefore, the new programme could be a tool that allows users to interact with a database designed for large amounts of information, the management of which requires a strict structure and rational access and processing.

The functions and outcomes for each item in the Farm-Key software programme

Animals

The functions are managing and tracking individual animals within the dairy farm. The outcomes are keeping records of animal identification, health status, breed, and age. Track milk production and monitor any health issues or activity patterns **(Figure 3)**.

Nutrition

The functions are planning and monitoring the nutrition requirements for the animals. The outcome is creating customized diet plans for each animal based on their specific needs. Keep track of feed types, quantities, and feeding schedules. Monitor the nutritional intake and adjust diets as necessary **(Figure 4)**.

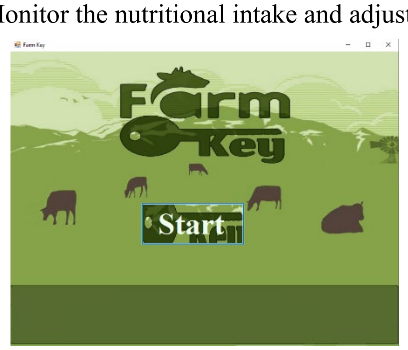


Figure 1. The start page of the farm key programme.

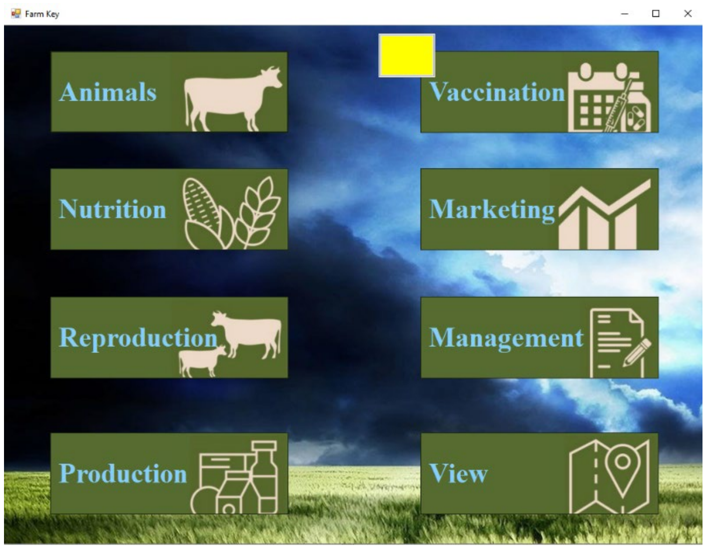


Figure 2. The eight items in the farm-key programme are animals, nutrition, reproduction, production, vaccination, marketing, management and map/view.

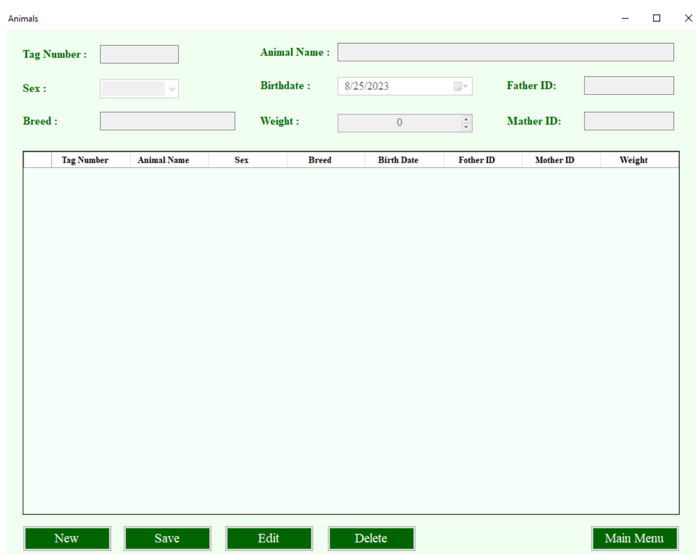


Figure 3. The animal item is intended for the purpose of maintaining comprehensive records pertaining to animal identification, health status, breed, age, and other relevant details.

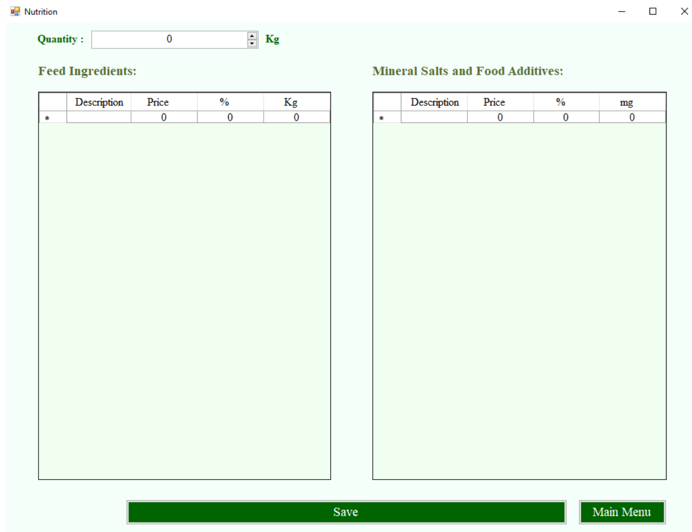


Figure 4. The nutritional item demonstrates an essential role in the strategic management and supervision of the nutritional needs of animals.

Reproduction

The function is to manage the reproduction process of the animals. The outcomes are keeping track of breeding cycles, fertility status, and mating records. Schedule and monitor artificial insemination or natural mating. Monitor pregnancy progress and record expected calving dates **(Figure 4)**.

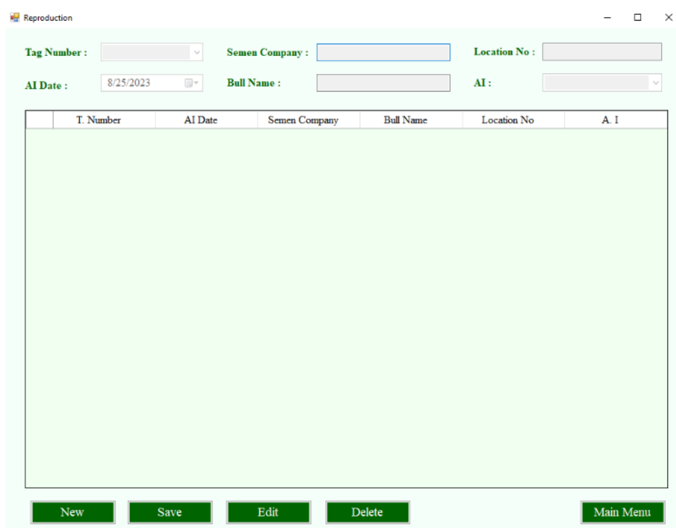


Figure 4. The reproductive item serves as a pivotal component in effectively overseeing and controlling the intricate process of animal reproduction.

Production

The functions are monitoring and analysing milk production on the dairy farm. The outcomes are recording daily milk yield from each cow and analysing trends in production. Also, tracking milk parameters such as fat and protein content, and measuring the milk quality by applying several tests, such as; Somatic Cell Count (SCC), Standard Plate Count (SPC), Preliminary in Cubation Counts (PCI) and Lab Pasteurized Count (LPC). Generate reports on milk production performance and identify any abnormalities **(Figure 5)**.

Figure 5. Production item, to monitor and analyse milk production on the dairy farm.

Vaccination

The function is managing vaccination schedules and health records. The outcome is recording the vaccination history for each animal. Set up reminders for upcoming vaccinations. Monitor overall herd health status and track any disease outbreaks. Generate vaccination reports for compliance purposes **(Figure 6)**.

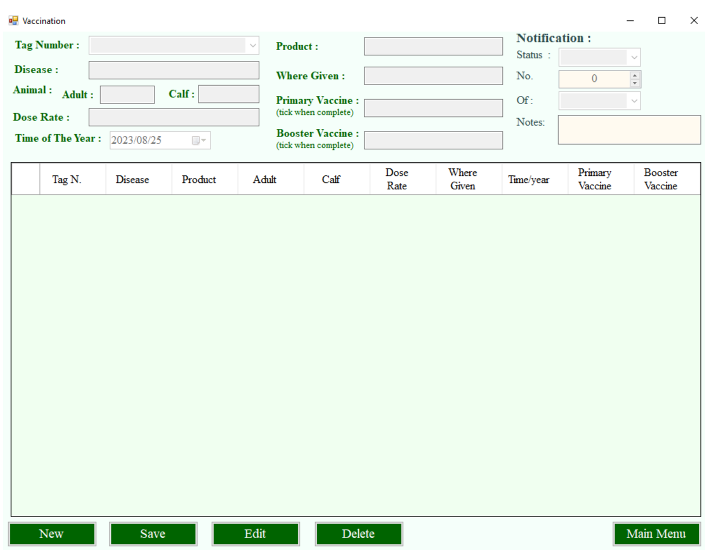


Figure 6. Vaccination item, to manage vaccination schedules and health records.

Marketing

The functions are tracking market activities and sales of dairy products. The outcomes are managing customer data and sales records. Track product inventory levels. Generate sales reports and analyse market trends. Monitor product pricing and promotions **(Figure 7)**.

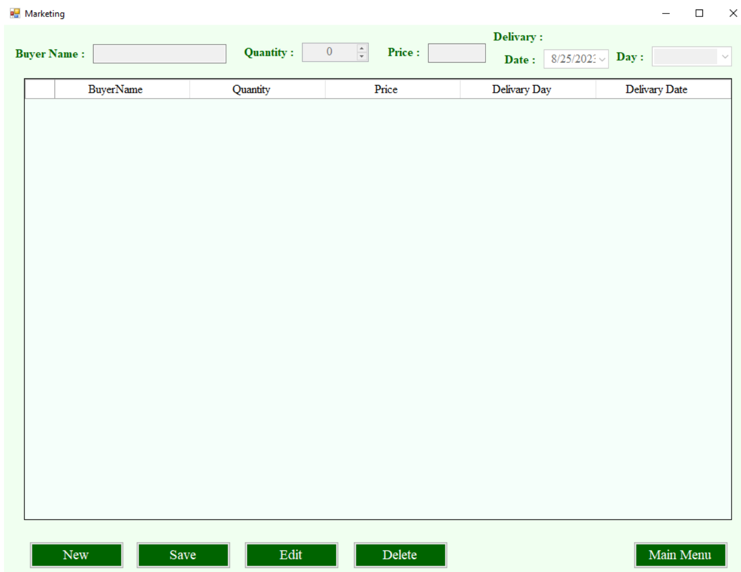


Figure 7. Marketing item, to track market activities and sales of dairy products

Management

The functions are assisting in overall farm management and decision-making. The outcomes are providing key metrics and performance indicators for the dairy farm. Monitor financial aspects such as expenses, revenue, and profitability. Generate reports on performance, efficiency, and cost analysis. Assist in long-term planning and business strategy **(Figure 8)**.

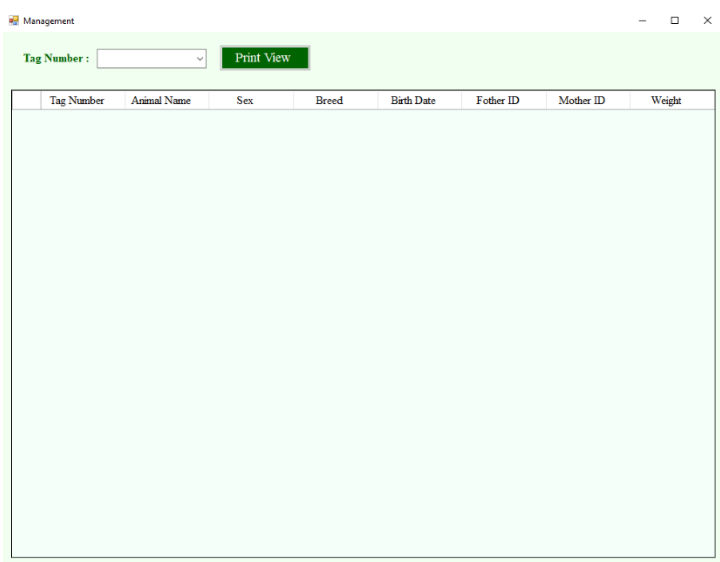


Figure 8. Management item, to assist in overall farm management and decision-making. There is an option to print all information for the herd on the farm in the current window.

Map/View

The functions provide a visual representation of the farm's layout and data. The outcomes are displaying an interactive map of the farm, including barns, pastures, and infrastructure. Overlay data such as animal locations, feeding stations, or milking stations. Assist in visual analysis of farm operations and resource allocation **(Figure 9)**.

Overall, the Farm-Key software program helps dairy farm managers plan and manage various practices and facilities, providing valuable insights, optimizing processes, and ensuring efficient farm operations.

Figure 9. Map/View item, to provide a visual representation of the farm's layout and data.

Discussion

The dairy industry has experienced significant advancements in milk yield and quality, thanks to superior germplasm, improved nutrition strategies, better healthcare facilities, and enhanced dairy husbandry practices (Omer 2022). The expansion of large dairy farms worldwide, particularly smart farms equipped with high-tech constructions, advanced devices and tools, and software programs, has further contributed to increasing productivity (Brito *et al*. 2021; Singh *et al*. 2021). However, the need for high-quality milk in larger quantities poses challenges for dairy farms, particularly in terms of labour availability and cost (Grasseni 2007; Mamane 2022). To address these challenges, the use of advanced software programs and engineered devices has become an alternative to reduce labour costs (Barile *et al*. 2022; Santos *et al*. 2022; Singh *et al*. 2022).

In recent decades, software programs have been developed to manage various aspects of dairy cow breeding, such as nutrition system management, reproduction planning, gynaecological and veterinary health care, and morphological and genetic evaluation of animals (Grasseni 2005; Maciuc *et al.* 2015). These software programs have revolutionized livestock farming by providing efficient management tools and expert-based solutions combined with advanced data analytics and artificial intelligence.

However, to ensure the effective utilization of these software programs and avoid sub-usage or misuse, it is crucial to examine breeders' problems and plan their usage according to the specific needs and resources of the farm (Samer 2010; Tummers *et al*. 2021). This involves identifying the departments to be automated, determining the data to be tracked, and allocating human resources accordingly. The flexibility and adaptability of the software programs allow for personalized analysis and management of breeding performances, enabling breeders to identify critical points and improve their practices (Maciuc *et al*. 2015; Kang *et al*. 2021; Tassinari *et al*. 2021).

In this context, the Farm-Key programme aimed to improve various dairy farming activities and welfare assessments, including milk production and quality, estrus, AI, and disease management. The use of advanced software programs and data technologies, combined with expert-based solutions, can bring substantial improvements to existing dairy farming practices.

The Farm-Key software program offers a comprehensive solution for managing dairy farms and optimizing various practices and facilities. With its range of functions and outcomes, Farm-Key enables dairy farm managers to effectively plan and monitor key aspects of their operations.

One of the crucial functions provided by Farm-Key is animal management. This feature allows managers to keep detailed records of individual animals, including identification, health status, breed, and age. The software also tracks milk production and monitors the animals' health issues or activity patterns. By having access to this information, managers can make informed decisions to improve the overall well-being and productivity of their animals.

Nutrition planning and monitoring is another important function offered by Farm-Key. Managers can create customized diet plans for each animal based on their specific nutritional requirements. The software keeps track of feed types, quantities, and feeding schedules, allowing for precise monitoring of the animals' nutritional intake. Any necessary adjustments to the diets can be made based on the collected data, ensuring that the animals receive optimal nutrition for their well-being and productivity.

The reproduction function of Farm-Key streamlines the management of the breeding process. Managers can easily keep track of breeding cycles, fertility status, and mating records. They can also schedule and monitor artificial insemination or natural mating. Monitoring pregnancy progress and recording expected calving dates helps in efficiently managing the reproduction process and ensuring the growth of the herd.

Farm-Key also offers monitoring and analysis of milk production on the dairy farm. The software records daily milk yield from each cow and analyses production trends. Additionally, it tracks milk parameters such as fat and protein content and conducts various tests to measure milk quality. Reports generated by Farm-Key provide valuable insights into milk production performance, enabling managers to identify any abnormalities and make informed decisions to optimize production.

The software program also helps manage vaccination schedules and health records. Managers can easily record vaccination history for each animal and set up reminders for upcoming vaccinations. Farm-Key enables monitoring of overall herd health status and tracking of disease outbreaks. Furthermore, the software generates vaccination reports for compliance purposes, ensuring that the farm meets industry standards.

Marketing activities and sales of dairy products are also simplified with Farm-key. The software enables tracking of market activities, customer data, and sales records. It also helps monitor product inventory levels and generate sales reports. Analysing market trends, product pricing, and promotions becomes easier, facilitating effective marketing strategies and maximizing sales.

Farm-Key contributes to overall farm management and decision-making with its management function. The software provides key metrics and performance indicators, enabling managers to monitor financial aspects such as expenses, revenue, and profitability. Reports on performance, efficiency, and cost analysis aid in making informed decisions and planning for the long-term success of the farm.

To provide a visual representation of the farm's layout and data, the Farm-key includes the map/view function. This feature displays an interactive map of the farm, highlighting barns, pastures, and infrastructure. Data such as animal locations, feeding stations, or milking stations can be overlaid on the map, facilitating visual analysis of farm operations and resource allocation.

Overall, Farm-key is a powerful software programme that assists dairy farm managers in planning and managing various practices and facilities. By providing valuable insights, optimizing processes, and ensuring efficient farm operations, Farm-key is an essential tool for modern dairy farming.

Conclusion

In conclusion, the development and utilization of advanced software programmes in dairy farming have revolutionized the industry by improving productivity, management efficiency, and animal welfare. The Farm-Key software programme, designed for dairy farm management, offers breeders a robust tool to plan, monitor, and optimize various aspects of their operations. With continued advancements and integration of new technologies, software programmes hold immense potential for the future of dairy farming.

Future vision

Farm-Key Software has been widely recognized as a highly effective tool for managing dairy farms. Its extensive range of features and functionalities has greatly assisted dairy farm managers in optimizing various practices and facilities. Considering the evolving landscape of technology and user preferences, there is a need to develop a future version of Farm-Key, called Farm-Key+, that is fully compatible with ISO standards and can run on Android devices. This upgraded programme will further enhance and streamline the management processes in dairy farms, ensuring maximum efficiency and convenience.

ISO Compatibility: The Farm-key+ software will be designed to comply with ISO standards, ensuring that dairy farm management processes align with international regulations and best practices. This feature will enable farms to achieve and maintain certification, making them more competitive in the global market.

Android Compatibility: Recognizing the increasing popularity of Android devices, Farm-Key+ will be optimized to run smoothly on these platforms. This will provide users with greater flexibility and convenience, allowing them to access and manage farm data anytime, anywhere, using their Android smartphones or tablets.

Enhanced User Interface: Farm-key+ will feature an upgraded user interface that is intuitive, user-friendly, and aesthetically pleasing. The layout will be optimized for touchscreen interactions and intuitive navigation, making it easier for users to access the software's various functions.

Advanced Analytics and Reporting: The analytics and reporting capabilities of Farm-Key+ will be enhanced to provide more comprehensive insights into farm operations. The software will generate detailed reports, including key performance indicators, financial analysis, production trends, and resource allocation. These reports will aid in decision-making, long-term planning, and continuous improvement of the dairy farm.

Data Integration and Interoperability: Farm-Key+ will prioritize data integration and interoperability, allowing seamless integration with other farm management systems and platforms. This will facilitate efficient data exchange and eliminate the need for redundant data entry, saving time and reducing errors.

Cloud-Based Storage and Backup: To ensure data security and accessibility, Farm-Key+ will utilize cloud-based storage and automatic backup functionalities. This will eliminate the risk of data loss and provide convenient access to farm data from multiple devices.

Real-time Monitoring and Alerts: Farm-Key+ will enable real-time monitoring of critical parameters such as animal health, milk production, feed consumption, and vaccination schedules. Managers will receive instant alerts and notifications on their Android devices, allowing them to promptly address any abnormalities or issues.

Machine Learning and AI Integration: To further enhance decision-making and automate certain processes, Farm-Key+ will integrate machine learning and artificial intelligence algorithms. These technologies will analyse historical data, identify patterns, and provide valuable insights and recommendations for improving farm operations and productivity.

Data and Programme Availability

The programme is available by contacting to Corresponding author: mengzhiwangyz@126.com

Statement of animal rights

"Not applicable"

Acknowledgements
"Not applicable"
Funding
This work was supported by the National 14th Five-Year Plan Key Research and Development Program (2024YFD1300204, 2023YFD1301705), high-end foreign experts from the Ministry of Science and Technology of China (G2023014066L), and the Priority Academic Program Development of Jiangsu Higher Education Institution (PAPD), P.R. China.
Conflicts of interest
The authors declare that they have no conflicts of interest.
Disclosure statement
The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.
Authors' contributions
N.N.A.M.H., H.M.H. A.A.S., and M.W. defined the research theme. A.A.S. designed methods. M.A., Y.G., Y.A., A.Z., A.A and O.A. organized the data. A.A.S., N.N.A.M.H., H.M.H. and M.W. interpreted the results and wrote the manuscript. All authors read, reviewed and approved the final manuscript.

Ethics declarations
Consent for publication
All authors gave their consent for publication.
Competing interests
The authors declare that there is no competing interest.

References

Barile V., Chiariotti A., Cenci F., La Mantia M.C. & Buttazzoni L. (2022) Precision Livestock Farming for Mediterranean Water Buffalo: Some Applications and Opportunities from the Agridigit Project. Safety, Health and Welfare in Agriculture and Agro-food Systems: Ragusa SHWA 2021 252, 41.

Brito L., Bédère N., Douhard F., Oliveira H., Arnal M., Peñagaricano F., Schinckel A., Baes C.F. & Miglior F. (2021) Genetic selection of high-yielding dairy cattle toward sustainable farming systems in a rapidly changing world. Animal, 100292.

Grasseni C. (2005) Designer cows: The practice of cattle breeding between skill and standardization. Society & animals 13, 33-50.

Grasseni C. (2007) Good looking: Learning to be a cattle breeder. Skilled visions: Between apprenticeship and standards 6, 47.

Kang X., Zhang X.D. & Liu G. (2021) A review: development of computer vision-based lameness detection for dairy cows and discussion of the practical applications. Sensors 21, 753.

Maciuc V., Creangă Ş., Maciuc D. & Vidu L. (2015) A New Software Programme for Data Management in Dairy Farms. Agriculture and Agricultural Science Procedia 6, 226-31.

Magnusson U., Boqvist S., Doyle R. & Robinson T.P. (2022) Animal health and welfare for sustainable livestock systems.

Mamane S. (2022) Challenges and strategies for the sustainable dairy farming in india. Editorial board.

Omer E.A.M. (2022) Designing Breeding Programs For Improving Milk Yield Performance Of Indigenous Genous Dairy Cattle In Sudan.

Samer M. (2010) Developing and implementing a software program for configuring three dairy corral designs. Journal of Experimental Sciences 1.

Santos C.A.d., Landim N.M.D., Araújo H.X.d. & Paim T.d.P. (2022) Automated Systems for Estrous and Calving Detection in Dairy Cattle. AgriEngineering 4, 475-82.

Singh A., Jadoun Y., Brar P.S. & Kour G. (2022) Smart Technologies in Livestock Farming. In: Smart and Sustainable Food Technologies (pp. 25-57. Springer.

Singh A.K., Bhakat C., Ghosh M.K. & Dutta T.K. (2021) Technologies used at advanced dairy farms for optimizing the performance of dairy animals: A review. Spanish journal of agricultural research 19, 5.

Tassinari P., Bovo M., Benni S., Franzoni S., Poggi M., Mammi L.M.E., Mattoccia S., Di Stefano L., Bonora F. & Barbaresi A. (2021) A computer vision approach based on deep learning for the detection of dairy cows in free stall barn. Computers and Electronics in Agriculture 182, 106030.

Tummers J., Kassahun A. & Tekinerdogan B. (2021) Reference architecture design for farm management information systems: a multi-case study approach. Precision Agriculture 22, 22-50.

The Estimation of Missing Data With Maximum Likelihood Methods In Animal Research

G. Tamer KAYAALP[1]
E-mail :tamer.kayaalp@gmail.com

[1]Cukurova University Agricultural Faculty Department of Animal Science Biometry and Genetic Section, Turkey

Abstract

The animals probably die in animal experiments. Hence, data were missed at this researches. This situation was produced most problems at experiment.

In this study first step multiple regression analysis was applied for full data. Second step we eliminated randomly 5 % of each independent variables. And then missing data were estimated by using Maximum Likelihood Method.

Keywords: Missing observation, Maximum Likelihood method, coefficient of determination.

Introduction

The study of missing values is one of the most important topics for regression analysis in animal researches. The observations were completed at beginning of experimental. But some experimental materials might be missed during experimental period. For example, in fattening performance some of the animals may die during the experiment because of environmental factors. In this situation, the analysis of experiment might be difficult (İkiz and et. al., 1996).

Anderson (1957) explained that parameters are estimated by using Maximum Likelihood method for data that has multiple variable normal distribution, in case some data are missed at experiment.

Buck (1960) estimated missing observations by improving a method that he gave his name. The researcher's results are similar to Least square method's results.

Glasser (1964) predicted parameters in the linear regression model belong to data set some of which are eliminated randomly in dependent variable. The researcher used Least square method in his study.

Afifi and Elashoff (1966) examined to predict estimators of regression equation which belong to missing observations and statistical properties of its different estimators.

The parameters were estimated by using Least Squares Method and modified Least Square method, in case X and Y variables have got missing observations. Residual mean of squares was used such as compared criteria value in this study (Afifi and Elashoff, 1966).

Haitovsky (1968) illustrated missing observations in artificial data derived via Monte Carlo simulation method for linear regression model by using Least square method and variance-covariance matrix method. Furthermore, the researcher emphasized that Least square method ineffective to estimate regression model's parameters when up to 15 % of all data disappears during experiment period.

Morison (1971) predicted missing observations at independent variable by using Maximum likelihood method and indicated both expected value and variance for Maximum likelihood estimators.

Beale and Little (1975) examined comparatively Maximum likelihood method and Buck's method for estimating the covariance matrix, which has quite stable performance through different patterns in a simulation study and suggested the former method.

Dempster et al. (1977) improved the EM algorithm to cope with missing observations, which are differ proportions, This algorithm is an iterative computational method to get a maximum-likelihood estimate when the data can be conveniently viewed as incomplete.

Donner (1982) predicted parameters of linear regression model, which have two variables (X_1 and X_2), for all data and missing observations.

Shih and Weisberg (1986) improved an algorithm that belongs to Maximum likelihood method and predicted parameters of linear regression model by using this algorithm. Here, Cook's statistics was used as compared test statistics.

Simonoff (1986) explained factors that influence the estimation, in case missing observation values are increased in data set.

Kayaalp (1999) has illustrated a method for multiple regression models with missing data. The statistical literature on missing data does not answer this question in general. In most articles data is ignored after being is assumed accidental in one sense or another. In some articles such as those concerned with the multivariate normal distribution (Anderson, 1957; Kayaalp and Çevik, 2000).

Atkinson and Cheng (2000) explained that The combinations of the forward search algorithm with the EM algorithm or multiple imputation is successful in detecting outliers from linear regressions models with an appreciable proportion of missing values and also provides a very robust estimation procedure.

The aim of this study is that regression equations are estimated by using maximum likelihood method for full and incomplete observations respectively. And then we are going to illustrate of estimating missing observations at experiment.

Material and Method

Material

In this study, used data, which belong to fattening performance, are recorded in Cukurova University, Agricultural Faculty, Animal Science Department, Feeds and Animal Nutrition Unit. There are sixty data for each variables used in analysis. Each variable's symbols has illustrated as following,

Y: Carcass weight
X_1: Body weight gain
X_2: Thigh weight

X_3: Forearm weight

Method

In this study, multiple regression model was used and its model is given in the Equation (1).

$$Y_i = a + b_1X_1 + b_2X_2 + b_3X_3 + e_i \quad (1)$$

Where,
Y_i : Dependent variable,
X_i : Independent variable,
a : This parameter must then be the value of Y when X is equal to zero (or intercept).
b_i : Regression coefficient (or slope)
e_i : Residuals ~ N (0, $\sigma^2{}_e$)

This model's parameters were estimated by using MINITAB statistic package program 13.1 Version.

Here, initially, the regression's parameters were estimated for all of observations. After that, five percent ratio of data of each X variables was randomly lost. The last process, multiple regression model's parameters were estimated by using Maximum Likelihood method. To obtain missing observations, three observations of each dependent variable were eliminated randomly.

Maximum Likelihood Method

1) Variance – covariance matrix is produced as following:

$$\sigma_{ij} = \begin{bmatrix} \sigma_{X_1X_1} & \sigma_{X_1X_2} & \sigma_{X_1X_3} \\ \sigma_{X_2X_1} & \sigma_{X_2X_2} & \sigma_{X_2X_3} \\ \sigma_{X_3X_1} & \sigma_{X_3X_2} & \sigma_{X_3X_3} \end{bmatrix}$$

The values of variance – covariance matrix are calculated from Equations (2), (3), (4), (5), (6), (7), (8) respectively.

$$\sigma_{X_1X_1} = \sum X_1^2 - (\sum X_1)^2 / n \quad (2)$$

$$\sigma_{X_2X_2} = \sum X_2^2 - (\sum X_2)^2 / n \quad (3)$$

$$\sigma_{X_3X_3} = \sum X_3^2 - (\sum X_3)^2 / n \quad (4)$$

$$\sigma_{X_1X_2} = \sum X_1X_2W_1W_2 - (\sum X_1W_1)(\sum X_2W_2) / n \quad (5)$$

$$\sigma_{X_1X_3} = \sum X_1X_3W_1W_3 - (\sum X_1W_1)(\sum X_3W_3)/n \quad (6)$$

$$\sigma_{X_2X_3} = \sum X_2X_3W_2W_3 - (\sum X_2W_2)(\sum X_3W_3)/n \quad (7)$$

If data were lost $W_i = 0$, else $W_i = 1$.

2) The covariance vector of Y variable is produced where covariance between X and Y variable is computed.

$$\sigma_{ij} = \begin{bmatrix} \sigma_{X_1Y} \\ \sigma_{X_2Y} \\ \sigma_{X_3Y} \end{bmatrix}$$

The covariance of this vector are calculated from Equations (8), (9), (10) respectively.

$$\sigma_{X_1Y} = \sum X_1Y\,W_1 - (\sum X_1W_1)(\sum Y)/n \quad (8)$$

$$\sigma_{X_2Y} = \sum X_2Y\,W_2 - (\sum X_2W_2)(\sum Y)/n \quad (9)$$

$$\sigma_{X_3Y} = \sum X_3Y\,W_3 - (\sum X_3W_3)(\sum Y)/n \quad (10)$$

3) The vector $\hat{b}' = (\hat{b}_1, \hat{b}_2, \hat{b}_3)$ is estimated from equation (11).

$$b' = (\sigma_{ij})^{-1}\sigma_{iY} \quad (11)$$

4) a value is estimated from equation (12).

$$\hat{a} = \overline{Y} - b_1\overline{X}_1 - b_2\overline{X}_2 - b_3\overline{X}_3 \quad (12)$$

5) The missing observations are estimated by using predicted regression equation.

6) Multiple regression analysis is completed by using Maximum Likelihood method, after missing observations' values are replaced in the analysis progress.

The regression analysis' table was given in Table 1 in order to test of significance for regression equation.

Table 1. Regression Analysis Table.

S.V.	**D.F.**	**S.S**	**M.S.**	**F**
Regression	P	$b_1S_{x_1y} + b_2S_{x_2y} + b_3S_{x_3y} = A$	$RMS = A/p$	RMS/MSE
Error	N-p-1	$SSE = S_{yy} - A$	$MSE = SSE/(N-p-1)$	
Total	N-1	S_{yy}		

Here,

p : The number of independent variable's value,

N : The number of observation value,
RMS : Means of square of regression
SSE : Sum of square of error,
MSE : Means of sum of square of error,

Coefficient of Determination (R^2), which belongs to predicted multiple regression model in this study, can be computed by using Equation (13),

$$R^2 = \frac{b_1 S_{x_1 y} + b_2 S_{x_2 y} + b_3 S_{x_3 y}}{S_{yy}} \tag{13}$$

Results

When there are all of data, by using Equation (1), multiple regression model's parameters were predicted and given as following equation,

Carcass weight (Y) = -3.16 + 5.67 Body weight gain (X_1) + 0.00626 Thigh weight (X_2) + 0.00207 Forearm weight (X_3)

In the model, although the first two parameters of the regression coefficients, b_1 and b_2, were statistically significant ($p<0.01$), last parameter, b_3, was not significant ($p>0.01$). The R^2 of predicted regression model was computed as 0.849.

The test of significance for predicted regression equation was given in Table 2.

Table 2. Regression Analysis Results for all data.

S.V	**D.F.**	**S.S**	**M.S.**	**F**
Regression	3	210.244	70.081	104.58**
Error	56	37.527	0.670	
Total	59	247.771		

**: p<0.01

Table 2 shows that predicted regression model is statistically significant ($p<0.01$). In addition, a parameter of the model is statistically significant, too.

When there are missing observations, by using Maximum Likelihood method, predicted results of multiple regression model's parameters were given as following.

Variances and covariances belong to X and Y variables were computed from Equation (2), (3), (4), (5), (6), (7), (8), (9), (10) respectively.

$$\sigma_{X_1X_1} = 0.002; \quad \sigma_{X_2X_2} = 66011.601; \quad \sigma_{X_3X_3} = 18066.060;$$
$$\sigma_{X_1X_2} = 4.289; \quad \sigma_{X_1X_3} = 1.781; \quad \sigma_{X_2X_3} = 28160.944;$$
$$\sigma_{X_1Y} = 0.0393; \quad \sigma_{X_2Y} = 485.624; \quad \sigma_{X_3Y} = 225.440$$

The vector, $\hat{b}' = (\hat{b}_1, \hat{b}_2, \hat{b}_3)$, was estimated by using Equation 11.

$$\hat{b}' = (\sigma_{ij})^{-1}\sigma_{X_iY} = \begin{bmatrix} 0.002 & 4.289 & 1.781 \\ 4.289 & 66011.601 & 28160.944 \\ 1.781 & 28160.944 & 18066.060 \end{bmatrix}^{-1} \begin{bmatrix} 0.0393 \\ 485.624 \\ 225.440 \end{bmatrix}$$

$$\hat{b}' = (\sigma_{ij})^{-1}\sigma_{X_iY} = (4.60167, \quad 0.00575, \quad 0.00306$$

a value was estimated from equation (12) as following,

$$\hat{a} = \overline{Y} - b_1\overline{X}_1 - b_2\overline{X}_2 - b_3\overline{X}_3 = -2.801$$

As a result, by using Maximum Likelihood method, when the parameters were replaced in the regression equation, the equation was determined as following equation,

Carcass weight (Y) = -2.801 + 4.60167 Body weight gain (X_1) + 0.00575 Thigh weight (X_2) + 0.00306 Forearm weight (X_3)

Determination coefficient (R^2) was computed as 0.871. In additional to the results, in this model, all of the parameters were statistically significant ($p<0.01$).

The test of significance for predicted regression equation was given in Table 3.

Table 3. By using Maximum Likelihood Method, Regression Analysis Results for data some of which are missed

S.V	D.F.	S.S	M.S.	F
Regression	3	184.225	61.408	105.88**
Error	47	27.227	0.580	
Total	50	211.452		

** : p<0.01

In Table 4, missing observations given in parentheses were estimated by using predicted regression model.

Table 4. By Using Maximum Likelihood Method Missing Values predicted

Body Weight Gain (X_1)		Thigh weight (X_2)		Forearm weight (X_3)	
Observed Values	Expected Values	Observed Values	Expected Values	Observed Values	Expected Values
0.32 (16) 0.35 (18) 0.34 (55)	0.36 0.37 0.52	2778 (15) 2412 (31) 3090 (49)	2820.18 2630.09 3279.34	1213 (7) 1303 (38) 1290 (56)	1053.92 985.38 2151.31

Discussion

Table 2 shows that predicted regression model was found significant for all data ($p< 0.01$). According to the results, the carcass weight may be estimated in predicted regression model by replacing body weight gain (X_1), thigh weight (X_2) and forearm weight (X_3). In case, there are missing observations, the derivation between estimated parameters and original parameters no much in predicted regression model for all data. Even some observations are missed during experiment period, missing observation can be estimated by using predicted regression model. Table 3 showed that the derivation between estimated values and original values no much in our study expect for body weight gain belong to 55. observation value, because the correlation coefficient is much between body weight gain and carcass weight as 0.78.

Maximum Likelihood method's activity is dependent to missing observation's proportion and to correlation value between independent variable (X) and dependent variable (Y). In general, if missing observations are up to 15 % of all data and correlation value between X and Y variables is up to 0.70, this method's activity is decreased and the derivation between observed and expected values will be increased.

References

İkiz, F., Püskülcü, H. ve Eren, Ş., 1996. İstatistiğe Giriş. İzmir, 435p.

Anderson, T.W., 1957. Maximum Likelihood Estimate for a Multivariate Normal Distribution When Some Observations are Missing. Jo Amer. Statist. Assoc. (52): 200-204.

Buck, S.F., 1960. A Method of Estimation of Missing Values in Multivariate Data Suitable for Use with An electronic Computer. J.Roy.Statist. Soc. (B22): 302-307.

Glasser, M., 1964. Linear Regression Analysis with Missing Observations Among The Independent Variables. J. Amer. Statist. Assoc. (59): 834-844.

Afifi, A.A. and Elashoff, R.M., 1966. Missing Observations in Multivariate Statistics I. Review of The Literature. J. Amer. Statist. Assoc. (61):595-604.

Haitovsky, Y., 1968. Missing Data in Regression Analysis. J. Amer. Statist. Assoc. (59): 834-844.

Morrison, D.F., 1971. Expectations and Variances of Maximum Likelihood Estimates of The Multivariate Normal Distribution Parameters with Missing Data. J. Amer. Statist. Assoc. (66): 602-604.

Beale, E.M.L. and Little R.J.A., 1975. Missing Values in Multivariate Analysis. J. Roy. Statist. Soc. Ser. (B37):129-146.

Dempster, A., Laird, N.M., Rubin, D.B., 1977. Maximum Likelihood Estimation From Incomplete Data Via The EM Algorithm. J. Roy. Statist. Soc. Ser. (B39):1-38.

Donner, A., 1982. The Relative Effectiveness of Procedures Commonly Used in Multiple Linear Regression Analysis for Dealing with Missing Values. The Amer. Statist. Assoc. (38):378-381.

Shih, W.J. and Weisberg, S., 1986. Assessing Influence in Multiple Linear Regression with Incomplete Data. Technometrics. (28): 231-239.

Simonoff, J.S., 1986. Regression Diagnostics to Detect Nonrandom Missingness in Linear Regression. Technometrics. (30): 205-214.

Kayaalp, G.T., 1999. Linear Regression Analysis with Missing Observations among The Independent Variables in Animal Breeding. TUBITAK Turkish J. Vet. and Anim. Sci. **(2): 149-151.**

Kayaalp, G.T. and Çevik F., 2000. The Estimation of Missing Values in Longitudinal Data Sets by Using Regression Methods in Biological Researches. Online Journal of Biological Sciences. (7): 678-679.

Atkinson, A:C and Cheng, T., 2000. On Robust Linear Regression with Incomplete Data. Computational Statistics & Data Analysis. (33): 361-380.

Comparison of Different Lactation Curves Models in Saanen Goats

G. Tamer Kayaalp[1,A*], Nazan Koluman[1,B]

1: Department Of Animal Science, Faculty Of Agricultural,Çukurova University, Turkey

[*]Corresponding Author: G.Tamer Kayaalp , Department Of Animal Science, Faculty Of Kayaalp, University, Turkey

tamer.kayaalp@gmail.com;

Abstract

Monthly 71 lactation records were collected from Saanen dairy goats in private farms. Three different lactation curve models were then comparatively examined for these data.The purpose of this study was to examine the models of lactation curve of purebred dairy goats and make some suggestions concerning appropriate mathematical model.

The following three models were used to describe the milk production:

R^2 values obtained from model (3) were all greater than those found from other models (1,2).In addition, the Mean Square Error (MSE) of model 3 was lower than the Mean Square Error (MSE) of the other 2 models.Hence model (3) was seen to be superior to other models.

Key words : *Lactation Curve, Persistency, Milk Yield, Coefficient of Determination, Multiple Regression Analysis.*

Introductıon

Characters of economic importance is livestock are influenced by numerous factors. If production is defined as a function of constants and variables, then a genetic control for these components may provide a useful device for livestock improvement.

So that a modelling of lactation curve in dairy cattle possesses some useful properties in its practical application. The characters which may be derived directly from the model of lactation curve are: the maximum daily milk yield, the time when the maximum daily milk yield reaches, the persistency of lactation that expresses the rate of decline in daily milk yield and estimated total milk yield (Kayaalp and Bek, 1991).

The goat is in the Capra genus of the Bovidae family. It is a horned ruminant. It has been highly valued by humans since the beginning of agriculture and animal husbandry. The goat was first domesticated in the region of the eastern Mediterranean called the "fertile crescent"

High productivity in terms of milk quantity and milk-percentage fat are the most desired characteristics in dairy goats. Dairy goats have an advantage over cows in that they have early development, high kid productivity, shorter gestation period and intergenerational period compared to other species, easy care and management, more resistant to diseases and parasites, have very high milk yields in relation to their live weight, and can give milk up to 10-15 times their own weight in one milking period (Güney, et.al.,2006).

The Alpine goat is a breed that takes its name and origin from the alps and is widely raised in France and the United States. Its ancestors are the Pashang goats that migrated to the alps approximately 15,000 years ago. The most well-known of the Alpine goats is the French alpine. Other members of this breed are the American and Swiss alpines. Dairying characteristics are prominent. The Alpine goat is a breed of Swiss origin and is known as excellent dairy goats with good shape and large teats. Most composite breeds contain the Alpine lineage.It attracts attention due to its large size and high milk yield and can easily adapt to most climates (Batra et.al.,1987).
Ferris et al. 1985, compared lactation curve patterns in dairy cattle to use as selection criteria.

In underdeveloped countries where cow milk is insufficient or cannot be consumed, goat milk and its products are very valuable as they constitute a daily source of food, protein, phosphorus and calcium for people.

The main purpose in animal husbandry is to increase the unit yield per animal. There are two ways to do this: improving the genotype and improving environmental conditions (Kayaalp and Bek 1991).

Damascus goats are considered the most locally important genetic resources in Syria, due to their higher productivity and reproductive ability under harsh environmental conditions. Therefore many countries in the world have important the Damascus goats to genetically improved their local breeds (Güney et al., 2006).

Ayasrah, et.al., 2013, estimated the lactation curve parameters and average milk yield in Syrian Damascus goats using Wood's model. They also estimated the heritability as 0.09+0.01.

Almasri, et.al., 2023, estimated the lactation curve parameters and average milk yield in Syrian Damascus goats using Wood's model.

Batra et al. (1997) estimated the parameters of different models of lactation curve in Holsthein cattle.

Shanks et al.(1981) studied the genetic aspects of the lactation curve.

Peak yield in goats usually occurs between 30-45 days after birth. To find the actual milk yield, milk should be measured every day, every milking throughout the lactation.

The term “lactation curve” is used to refer to the curve representing the ratio of lactation duration and milk yield (Almasri et.al,2023).

Takma, et.al. (2009) stated that many methods are used in determining the shape of the lactation curve and the model/models that best express lactation in Saanen and Bornova goats.

The daily yields determining the shape of the lactation curve of dairy cows are affected by genetic and environmental factors such as body weight, age of cow, dry period, rations, season, temperature and humidity (Schmidt and Van Vleck, 1974). The parameters of the lactation curve could be changed through selection (Shank et. al.,1981) changing the lactation shape by selection is small.

The first lactation curve model was introduced by Wood in 1967. Later, lactation curve models were studied by Grossman et al (1986), Goodall (1985), Nelder (1966) and many other researchers.

Kayaalp et al. (2025) comparatively examined the lactation curve models in Damascus goats.

Materıals And Methods

Monthly 71 lactation records were collected from Saanen dairy goats in private farms. Three different lactation curve models were then comparatively examined for these data.The purpose of this study was to examine the models of lactation curve of purebred dairy goats and make some suggestions concerning appropriate mathematical model The following three models were used to describe the milk production:

$Y_t = a\, t^{b}\, e^{-ct}$

$Y_t = a + b (t) + c (t^2$

$Y_t = a + b (t) + c (t^2) + d (t^3)$

Where,

Y_t : Milk yield on day t.,

a: Scaling factor to represent yield at the beginning of lactation,

b, c and d are factors associated with the inclining and declining slopes of the lactation curves.

A logaritmic transformation of the above models were carried out than the parameter estimations were made by using general multiple regression estimation techniques.

The parameters in equation were estimated, using the MINITAB statistical package programme.

The models were compared by using Coefficient Detemination value (R^2) and Mean Squre Error (MSE).

Results

The regression equations were estimated in turn as folows:

For Model 1 :

$\text{Ln } Y = \ln (0.3539) + (0.3900) \ln (t) – (0.1040) (t)$

For Model 2 :

$Y = 1.1164 + (0.2454) (t) – (0.0294) (t^2)$

For Model 3 :

$Y= 0.339 + (1.341) (t) - (0.4494) (t^2) +(0.0470) (t^3)$

The regression analysis tables of equation are given in Tables 1, 2, 3.

According to Table1, the R^2 value of estimation equation at Model 1 was 41.81% and all parameters,(a, b,c) were significant ($p < 0.01$).

Table 1. The Regression Analysis of Model 1

Term	Coef.	SE Coef.	t Value	P-Value
Constant (a)	0.3539	0.0367	9.65**	0.000
b	0.3900	0.09610	4.06**	0.000
c	-0.1040	0.03940	-2.64**	0.010

** : $p < 0.01$

It is seen from Table 2, R^2 value of estimation equation was found 30.67% . a and b parameters were significant ($p < 0.01$) . But c parameter was significant ($p < 0.05$)

Table 2. The Regression Analysis of Model 2

Term	Coef.	SE Coef.	t Value	P-Value
Constant (a)	1.1164	0.0952	11.72**	0.000
b	0.2454	0.0736	3.33**	0.001
c	-0.0294	0.0123	-2.40*	0.019

*: $p < 0.05$

** : $p < 0.01$

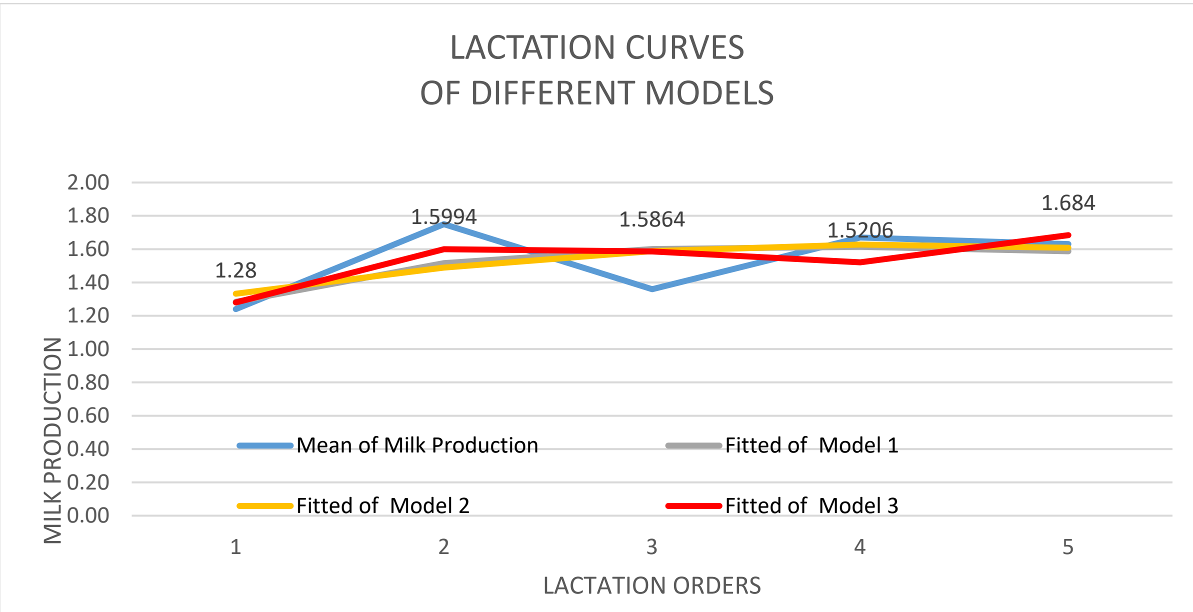
Table 3 indicates that the R^2 value of estimation equation was 46.96 % .a parameter was not significant ($p > 0.05$) but other parameters b, c and d of the equation were significant ($p < 0.01$).

Table 3. The Regression Analysis of Model 3

Term	Coef.	SE Coef.	t Value	P-Value
Constant (a)	0.3390	0.191	1,78	0.08
b	1.3410	0.250	5.36**	0.000
c	-0.4494	0.0932	-4.82**	0.000
d	0.04700	0.0104	4.54**	0.000

** : $p < 0.01$

Estimation values which were obtained from regression equations for all models and the curves of estimated and observed values were formed. These curves given as Figure 1.



Looking at Figure 1, it is seen that the predicted values in 3rd model are closer to the actual values.

Discussion

In this study, lactation curve parameters of third model was different**.** The coefficient of determination of the 3rd model was higher than the other two models.

The fitted curves from first and second models displayed underestimated milk yields at the beginning of the lactation. Sakul and Boylan (1992) explained this problem reporting that possible cause for such underestimation was resulted in delayed collection of milk data when the curve begins to decline.

Moreover, third model fit the Saanen goat data better than the first model, in other words. This finding is consistent with results of the Montaldo et al. (1997) revealed that the first model over predicts milk production during early and late lactation.

Generally, the Wood model (Model 1) provides a good fit to the lactation data in dairy cattle, while the 3rd model provides a better fit to the lactation data of dairy goats.

In the study conducted by Kayaalp et al. (2025) on Damascus goats, Model 3 was the best fitting model.

R^2 values obtained from model (3) were all greater than those found from other models (1,2).In addition, the Mean Square Error (MSE) of model 3 was lower than the Mean Square Error (MSE) of the other 2 models.Hence model (3) was seen to be superior to other models.

References

Almasri, O., Abon-Bakir, S.,İbrahim, M., Kahil, O., Asaad, Z., Ghoush, M. and Awad, M. A., 2023. Lactation Curve and Milk Production Traits of Syrian Damascus Goats. Egyptian J. Anim. Prod. 60(1): 7-16.

Ayasrah, E.M., Bakr, A. and Ibrahim, A.M., 2013. Characteristics of Lactation Curve in Damascus Goats in Jordan. J. Animal and Poultry Prod. Mansoura Univ. 4(8): 479-491.

Batra, T. R., Lin, C. Y., Mcallister, A. J., Lee, A. J., Roy, G. L., Vessely, J. A., Wauthy, J. M., Winter, K. A. 1987. Multitrait Estimation of Genetic Parameters of Lactation Curves in Holstein Heifers. J. Dairy Sci. 70:2105–2111.

Goodall, E. A., 1985. Bayesian Estimation of Lactation Curve of A Dairy Cow.Animal Production 40:189-193.

Grossman, M., Kuck, A. L., Norton H. W. 1986. Lactation Curves of Purebred and Crossbred Dairy Cattle. J. Dairy Sci. 69:195–203.

Güney, O. and Torun, O., Ozuyanik, O. and Darcan, N., 2006. Milk Production, Reproductive and Growth, Performance of Damascus Goats Under Northern Cyprus Conditions. Small Ruminant Research 65: 176.179.

Kayaalp,G.T. and Bek, Y. 1991. Laktasyon Eğrilerinin Biyometrisi. Çukurova Üniversitesi Fen Bilimleri Enstitüsü Dergisi 4(2) : 15-28.

Kayaalp, G. T., Koluman, N. and Vurana, G., 2025. The Comparision of Different Lactation Curves Models in Damascus Goats.Turkish Journal of Agriculture Food Science and Technology.13(6):1615-1617.

Montaldo, H., A. Almanza and A. Juarez, 1997. Genetic Group, Age and Season Effects on Lactation Curve Shape in Goats. Small Rumin. Res., 24: 195-202.

Nelder, J.A., 1966. Invers Polynomials A Useful Group of Multi-Factor Response Functions. Biometrics 22: 128-141.

Sakul, H. and W.J. Boylan, 1992. Lactation Curves for Several Us Sheep Breeds. Anim. Prod., 54: 229-233.

Schmidt, G. H. and Van Vleck, L. D. 1974. Principles of Dairy Science. Freeman and Company, San Francisco.

Shanks, R. D., Berger, P. J., Freeman, A. E., Dickinson F. N. 1981. Genetic Aspects of Lactation Curves. J. Dairy Sci. 64:1852–1860.

Takma, Ç., Akbaş, Y. and Taşkin, T. 2009. Modeling Lactation Curves of Turkish Saanen and Bornova Goats. Asian Journal of and Veterinary Advances, 4(3):122-129.

Wood, P.D .P., 1967. Algebraic Models of The Lactation Curve in Cattle. Biometrics 216:164-165.

Effect of Microwave oven Drying on some Nutritional and Anti-nutritional Content of Pretreated Paw-paw (*Carica Papaya*) Pulp Using Response Surface Methodology

Elijah George Ikrang*[1], Akindele Folarin Alonge[1],Mfrekemfon Godswill Akpan[1]

[1]Department of Agricultural and Food Engineering, University of Uyo, Nigeria

*Corresponding Author elijahikrang@uniuyo.edu.ng

Abstract

This study was conducted to investigate the effect of pretreatment and microwave oven drying on the nutritional and anti-nutritional content of Paw-paw (Carica papaya) pulp using response surface methodology (RSM). The response surface method used had 3 factors at 2 levels with full factorial central composite design used for the design matrix. The independent variables(factors) were Blanching Time (BTime), Ultrasound Time (UTime) and Ultrasound Energy (UEnergy). The Pawpaw fruit (C*arica papaya*) samples were purchased from Itam Market, Uyo, Akwa Ibom State, Nigeria. The samples were washed with clean water thoroughly removing all dirts and placed on a flat clean kitchen plastic tray and peeled vertically. After peeling, the pawpaw fruit was sliced into two halves vertically to enable the removal of dark brown seeds. The sample were then cut into 4mm to 6mm.thickness and 5mm x 6mm size in preparation for pretreatment and microwave oven drying. The thickness was 3mm. The pretreatment followed the outlined design matrix and thereafter was dried in a microwave oven. The drying temperature for Microwave Oven was 60^0C and pretreatment blanching temperature was 90^0C. The pawpaw slices were dried and monitored for every 30minutes till the moisture content was at equilibrium with the environment. The average sample weight for each of the 15 (fifteen) experimental runs were 50g. The response variable considered in the study were nutrient - Vitamin-C, Carotene; Minerals; Iron, Potassium and Anti-nutrients- Phytate and Oxalate content of the pulp. It was observed that the fresh paw-paw pulp had the following composition: Vitamin-C; 105mg/ml; Carotene; 43.90mg/ml, Iron; 0.36mg/ml, Potassium; 167mg/ml, Phytate; 0.95mg/ml and Oxalate; 0.38mg/ml. The dried pretreated paw-paw pulp had the following nutritional and anti-nutritional composition; Vitamin-C; a range of 112.73mg/ml to 118.12mg/ml, Carotene; a range of 50.28 to 50.45mg/ml, Iron; a range of 0.48mg/ml to 0.61mg/ml, Potassium; a range of 177.75mg/ml to 183.27mg/ml, Oxalate; a range of 0.27mg/ml to 0.53mg/ml and Phytate; a range of 0.89mg/ml to 1.31mg/ml. It was observed that the dried samples nutrient and anti-nutrients content increased as compared to the fresh samples.

Introduction

Background of the Study

Carica papaya fruit is obtained from the commonly grown papaya tree also popularly referred to as papaw or paw-paw tree. It is one of the species in the genus *Carica* of the family *Caricaceae* (Chávez, *et al.,* 2017). About 43% of the Worlds papaya production in 2020 was produced in India. The papaya tree is small, sparsely branched with a sole stem growing from 5 to 10 m in height. It also has spirally arranged leaves arranged around the top of the canopy. The lower trunk shows indications where leaves and fruits were borne. Usually the leaves are large, 50–70 cm in diameter, with seven lobes (Heywood, 2007).

Every papaya plant parts contain latex (milky fluid that coagulates on exposure to air, containing proteins, sugars, oils, tannins, resins, alkaloids, starches, , and gums) in articulated laticifers. Papayas are dioecious (contains only male or female reproductive structures in its flowers) (Ronse, 2010). In Asia the latex is employed as an abortifacient, antiseptic for wound dressing and a cure for dyspepsia, while in Africa, the root infusion is reputed for treating venereal diseases, piles, and yaws. In Cuba, the latex is used in the treatment of psoriasis, ringworm, and cancerous growth (Sharmeen, *et al,* 2012)

. Its fruits and seed extracts are known to have anti-bacterial activity against Staphylococcus aureus. (Sharmeen, *et al,* 2012). Papaya fruit contains vitamins A and C, small quantity amount thiamine, riboflavin, calcium, iron, potassium, magnesium and sodium. When unripe papaya is a good source of carbohydrates, vitamins and proteins, and the content decreases as it ripens (Chukwuka *et al,* 2013). Papaya at different stages is a good source of vitamin A and mineral elements (Ca, Mg, Na and K) (Chukwuka *et al.,* 2013). Unripe pawpaw contains the highest amount of

all the anti-nutrient such as saponin, alkaloid, tannin, flavonoid and phenol. (Chukwuka *et al.,* 2013). Papaya acts as an antioxidant, antimicrobial, anti-carminative, anti-cancer, and has hepato-protective, immunological, and other therapeutic attributes (Saeed, *et al.,* 2014).
Papaya fruits can be eaten as breakfast and also as an ingredient in jellies, preserves, or cooked in various ways (Vyas, *et al.,* 2016). The juice makes a popular beverage, young leaves, shoots and fruits cooked as vegetable. In cosmetic industries, the plants and plant extracts are mostly used for various purposes such as; moisturizing, whitening, tanning, color cosmetic, sunscreens, radical scavenging, anti-oxidant, immune stimulant, washing, preservatives, and as thickeners (Vyas, *et al.,* 2016).
In various researches, various pretreatments have been applied to various drying methods of agricultural materials such as sulfuring or sulfite dip, salt solution, blanching, blanching and sulfiting, dipping in 0.5% ascorbic acid solution chilling, and freezing, blanching, dipping and sulfiting, sucrose, blanching in hot water at 85°C steam, water. lemon juice, salt solution, honey dip (Minh, 2019). The basic drying methods used in the drying of fruits include sun and solar drying, atmospheric drying including batch continuous methods and sub-atmospheric dehydration (vacuum, belt/drum and freeze dryers) (Osunde, 2017).
In recent times the scope has been extended to incorporate the use of low-temperature and low-energy methods like osmotic dehydration. As drying process involves transient heat and mass transfer, the choice of the method depends on various factors which should be taken into consideration (Haghi and Amanifard, 2008).

The anti -nutritional and nutritional content of Carica papaya fruit vary with different drying methods as these methods makes use of many parameters and mode of operation. Since heat affects nutrients available in a dried fruits using various drying mode, microwave drying method with pretreatment on pawpaw fruit was chosen for this work. The objective of this study. are to evaluate the nutritional and anti- nutritional contents of *carica papaya* fruit as affected by microwave oven drying using response surface methodology (RSM) The specific objectives are;
1.To determine some nutritional and anti-nutritional content of pretreated Carica papaya fruit using Microwave oven at 60^0C.
2.Develop response surface graphs for the microwave drying of the fruits.

Materials and Method

The experiment design had three factors at two levels from a central composite design resulting in (fifteen) 15 runs with duplicate. The factors were blanching rime(BTime), ultrasound time(UTime) and ultrasound Energy(UEnergy). This experiment design followed the design Metrix from MiniTab (version 21) software as shown on Table 1.o.
Materials needed for the work are knife, distill water, food slicer, wire mesh, stainless metal tray. digital pocket thermometer and microwave oven
Sample Collection: The Pawpaw fruit (*carica papaya*) samples were purchased from Itam Market, Uyo,Akwa Ibom State, Nigeria. Samples purchased numbered two (2) weighing 1.160kg and 830g, total weight being 1.99kg.

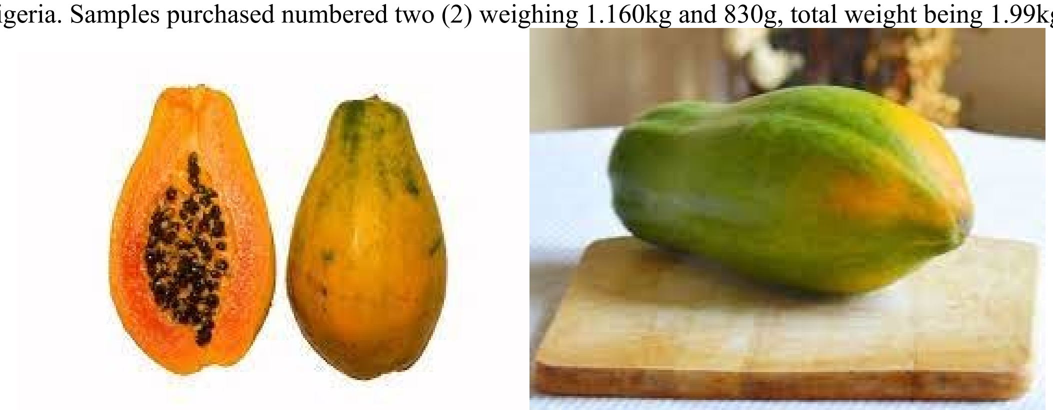


Figure1.1 Papaya (pawpaw)

Sample Preparation
The samples as shown in Figure 1.1 were washed with distilled water thoroughly removing dirt. Sample was placed on a flat clean plastic tray and peeled vertically. After peeling, the pawpaw was sliced vertically to enable the removal of dark brown seeds, also the peels and the seeds were discarded. The pawpaw was then cut into different sizes to enable thin layer pretreatment and drying. The pawpaw was sliced into thin layer dimensions using Food slicer machine (SL524B) 220-240V 50Hz,150W). The slices varied between 4mm to 6mm. in length and breadth with a

thickness of 3mm. After slicing, the weight of the sample containers were recorded. The weight of the samples were also noted. Weight of sample in container – weight of container was noted for each of the fifteen (15) samples. The samples were then subjected to pretreatment prior to drying

Pretreatment

The various pretreatment factors were blanching rime, ultrasound time and ultrasound Energy. The pretreatment procedure was done sequentially prior to microwave drying as shown in Table1.0

Table 1.0 Pretreatment arrangement with Design Matrix.

Runs	UTime (mins)	Energy (%)	BTime (sec)
1	5	80	60
2	7	100	30
3	5	80	30
4	5	100	60
5	7	100	90
6	3	100	30
7	3	60	90
8	7	80	60
9	7	60	90
10	3	60	30
11	3	80	60
12	5	60	60
13	5	80	90
14	3	100	90
15	7	60	30

Blanching time: The pawpaw fruit samples were blanched at 90^0C at different time intervals ranging from; 30, 60, to 90sec.

Ultrasound time: This ranged from; 3, 5 to 7 mins. Ultrasound energy; This ranged from 60, 80 to 100% energy level.

Drying Method

Microwave Oven

The weighed samples kept in an air tight containers were arranged on a wire mesh tray to be dried in the Microwave oven. ss shown in Figure 1,2 The drying temperature for Microwave Oven was 60^0C. The pawpaw slices dried were monitored at 30minutes interval for weight reduction until equilibrium moisture content was obtained.

Figure.1.2 Pawpaw slices in Microwave Oven.

The paw-paw slices were arranged in a wire mesh and placed at the different tray slot for drying and the microwave door/latch was closed and the timer was set for drying to start.

Nutritional Analysis

The nutritional content analysis was carried out on fresh and dried samples on the 15 samples per batch to observe the drying operation.

Proximate analysis: Proximate composition of the samples was carried out using official AOAC (2005) methods for moisture content, crude fat, crude fibre, ash, crude protein. A nitrogen-to protein conversion factor of 6.25 was used. Carbohydrate content was calculated by difference. The iron content of the sample was determined by using the sample ash. The ash was placed in porcelain crucibles, then a few drops of distilled water were added, followed by 2ml of concentrated HCl. 10ml of 20% HNO3 was added, then evaporated on a hot plate. The samples were then filtered through a Whatman filter paper into a 100ml volumetric flask. The mineral element, iron, was determined by an atomic absorbance spectrophotometer (AOAC, 2005). The determination of other mineral content was carried out by the use of destruction method following AOAC method 99911 (2002). Determination of phytates and oxalates were done by method used by. Mwanri et. al. 2018. Determination of Vitamin C (Ascorbic Acid) was done by method of Hussian *et al*. (2006).

Results and Discussion

Results for Effects of Blanching time, Ultrasound time and Ultrasound energy on the Nutritional and anti-

Nutritional content

of Paw-Paw (*Carica papaya*)

The summary of the proximate, nutritional and anti-nutritional content of untreated Paw-paw pulp are shown on Table2. The effect of pretreatment (Blanching time; 30, 60 and 90seconds, Ultrasound time; 3, 5 and 7 mins, Ultrasound Energy; 60, 80 and 100%) and Microwave drying at 60^0C selected in analyzing the nutritional and anti-nutritional content of Paw-Paw pulp is presented in Table .3

Table 2 Proximate and nutritional Composition of untreated Paw-paw Samples

S/N	Proximate comp.	Unit (%)
1	Moisture	78.03 ±0.23
2	Lipid	0.20±0.03
3	Fibre	0.70±0.13
4	Ash	0.88±0.53
5	Protein	0.37±0.03
	Nutrient	**Unit (mg/100g)**
1	Carotene	43.90±0.23
2	Vitamin C	105±0.13

3	Potassium	167±0.87
4	Oxalate	0.38±0.03
5	Phytate	0.95±0.09
6	Iron	0.36±0.04
7	Manganese	0.04±0.01

Table 3 Effects of Blanching time, Ultrasound time and Blanching Temperature on the Nutritional and Anti-Nutritional content of Paw-Paw (*Carica papaya*).

Runs	BTime (sec)	UTime (mins)	UEnergy (%)	Oxalate (Mg/100g)	Phytate (Mg/100g)	Potassium (Mg/100g)	Iron (Mg/100g)	Carotene (Mg/100g)	Vitamin C (Mg/100g)
1	60	5	80	0.38±0.03	1.11±0.03	178.04±0.07	0.51±0.05	50.35±0.07	114.00±0.01
2	30	7	100	0.30±0.09	0.89±0.03	180.07±0.01	0.56±0.02	50.38±0.033	118.12±0.07
3	30	5	80	0.43±0.04	1.16±0.07	178.11±0.07	0.51±0.07	50.40±0.07	115.78±0.03
4	60	5	100	0.35±0.06	0.95±0.09	179.77±0.01	0.57±0.05	50.32±0.031	113.97±0.07
5	90	7	100	0.28±0.07	0.91±0.05	183.27±0.07	0.63±0.032	50.28±0.03	112.91±0.037
6	30	3	100	0.32±0.05	0.98±0.03	181.00±0.033	0.58±0.05	50.45±0.11	116.11±0.035
7	90	3	60	0.48±0.03	1.29±0.035	177.75	0.50±0.11	50.31±0.18.	113.89
8	60	7	80	0.36±0.07	1.18	178.90±0.03	0.53	50.37±0.11	116.21±0.07
9	90	7	60	0.45±0.07	1.23±0.033	179.00	0.49±0.05	50.33±0.71	112.73
10	30	3	60	0.53±0.012	1.31±0.13	178.21±0.033	0.48±0.11	50.39	114.89±0.07
11	60	3	80	0.42±0.011	1.24	178.76	0.54±0.035	50.37	114.60
12	60	5	60	0.46	1.21±0.11	177.90±0.11	0.49±0.13	50.30±0.035	114.31±0.11
13	90	5	80	0.43±0.035	1.08±0.13	178.57	0.55	50.34±0.51	113.46
14	90	3	100	0.27±0.13	1.24	181.75	0.59±0.033	50.32	113.92±0.11
15	30	7	60	0.49±0.13	1.26±0.035	178.12±0.11	0.50	50.38±0.15	113.94±0.035

Effect of Blanching Time and Ultrasound Time on oxalate anti -nutrient.

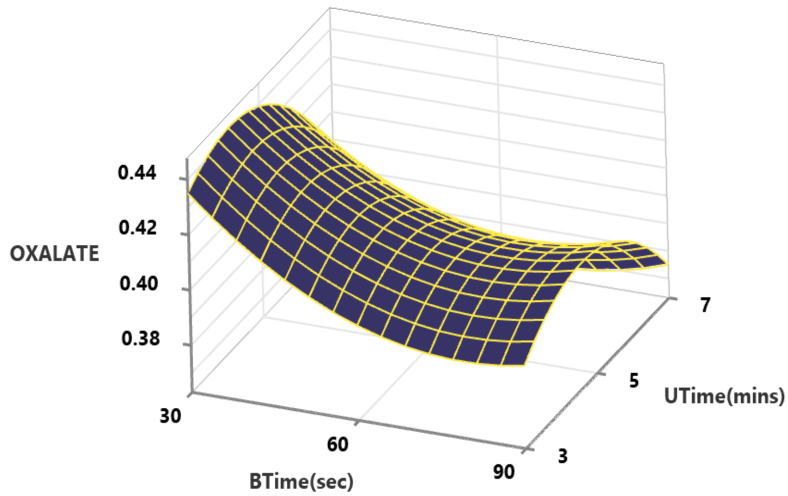


Figure. 1.2 Response surface graph for effect of Blanching Time (BTime) and Ultrasound Time (UTime) on Oxalate**.**

From the graph of Figure 1.2, it is observed that there is significant effect of both ultrasound time and blanching time on Oxalate. It is observed that the Oxalate level experienced a significant increase between Ultrasound time of (3 – 5 mins) and a decline was observed from blanching time of (5-7 mins). From this, it shows that, increase in Ultrasound time above 5 mins will lead to decrease in Oxalate level with Blanching time (BTime). This is in line with the work done by Ikrang and Umani 2019. From the graph, it is observed that there is a decline in Oxalate level as the Blanching time increases with Ultrasound time (UTime).

Effect of Blanching Time (BTime) and Ultrasound Time (UTime) on Phytate.

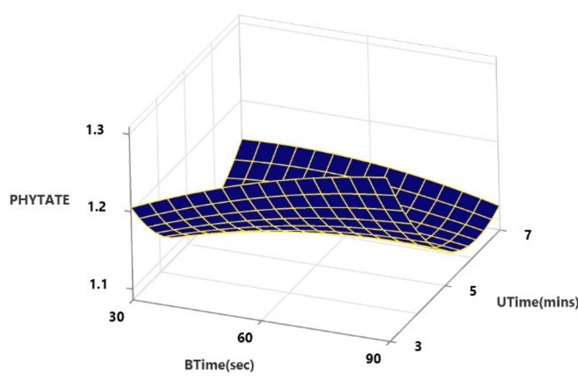


Figure. 1.3 Response surface graph for

From the graph, Figure1.3 it is observed that there is significant effect of both ultrasound time and blanching time when combined together on Phytate. It is observed that the phytate level experienced a significant increase as blanching time increased. From this, it shows that, increase in Blanching time leads to increase in phytate level with Ultrasound time (UTime). From the graph, it is observed that there is a decline in phytate level as the Ultrasound time increases with Blanching time (BTime). From the graph, it showed that, with increase in Ultrasound time (UTime), phytate dropped from highest point to the mid-point of 5 mins and then increase again.

Effect of Blanching Time (BTime) and Ultrasound Time (UTime) on Potassium.

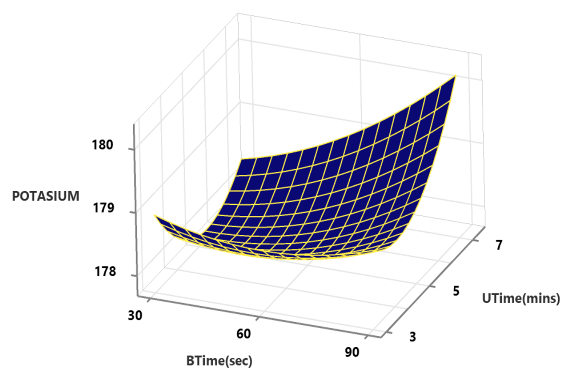


Figure. 1.4 Response surface graph for effect of Blanching Time (BTime) and Ultrasound Time (UTime) on Potassium.

From the graph, Figure 1.4 it is observed that there is significant effect of both ultrasound time and blanching time on Potassium. It is observed that the potassium level experienced a significant increase as Ultrasound time increases. From this, it could be seen that, increase in Ultrasound time leads to increase in Potassium level. Also, it is observed that there is a decline in Potassium level as the Blanching time increases from 3- 7mins with Ultrasound time (UTime). This finding is similar to the work done by Ekanem et.,al., 2020. From the work, it showed that, increase in Blanching time (BTime) leads to a decline in potassium level with Ultrasound Time (UTime).

Effect of Blanching Time (BTime) and Ultrasound Time (UTime) on Iron.

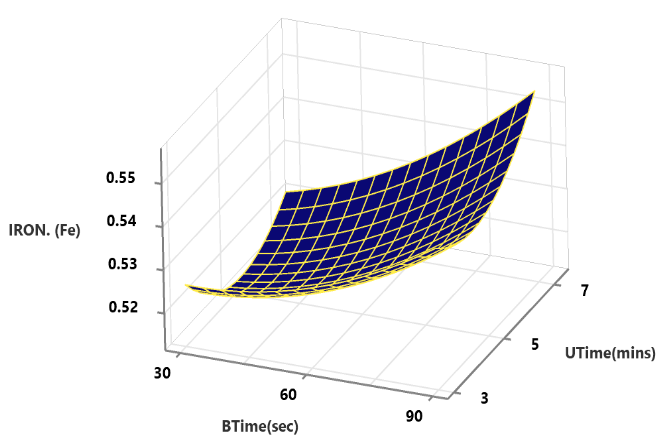


Figure. 1.5. Response surface graph for effect of Blanching Time (BTime) and Ultrasound Time (UTime) on Iron.

From the graph, Figure 1.5 it is observed that there is significant effect of both ultrasound time and blanching time when combined together on Iron. It is observed that the Iron content experienced a significant increase as blanching time increase from 30 sec- 90 sec. From this, it concludes that, increase in blanching time leads to increase in Iron level with ultrasound time **(UTime**). From the graph, it is observed that there is an increase in Iron level as the Ultrasound time increases from 3- 7mins with Blanching time **(BTime).** This observation is in line with the work carried by Fakayode and Ajav 2016. From this, it showed that, increase in Ultrasound time **(UTime)** leads to a significant increase in Iron level with Blanching Time **(BTime).**

Effect of Blanching Time (BTime) and Ultrasound Time (UTime) on Vitamin C.

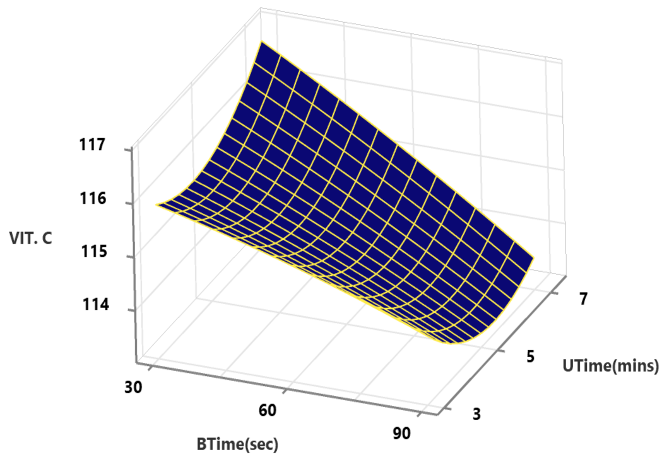


Figure. 1.6 Response surface graph for effect of Blanching Time (BTime) and Ultrasound Time (UTime) on Vitamin C.

From the graph, Figure 1.8 it is observed that there is significant effect of both ultrasound time and blanching time when combined together on Vitamin C. It is observed that the Vitamin C level experienced a significant decrease as blanching time increase from 30 sec- 90 sec. From this, it could be observed that, increase in Blanching time leads to decrease in Vitamin C level with Ultrasound time **(UTime**). This finding is in line with the observations by Ossom et al., 2020. From the graph, it is observed that there is a decline in Vitamin C level as the Ultrasound time increases from 3- 5mins and Vitamin C content experienced an increase as Ultrasound time increased from 5-7min with Blanching time **(BTime).**

Conclusion

The Paw-paw fruit thin layer slices were dried using Microwave Oven at 60^0C. Effects of the drying method on the nutritional and anti-nutritional properties of Paw-paw *(carica papaya)* sing response surface methodology was analyzed in this research study. Based on the results, the following conclusions were made:

. From the result of the work, it shows that, increase in Ultrasound time above 5 mins will lead to decrease in Oxalate level with Blanching time (BTime). It was also observed that there is a decline in Oxalate level as the Blanching time increased. Moreover, it was observed that there is a decline in phytate level as the Ultrasound time increases with Blanching time (BTime). It also showed that, with increase in Ultrasound time (UTime), phytate dropped from highest point to the mid-point and then increased again.

After pretreatment and subsequent drying, of samples in the micro wave oven the nutrients and anti-nutrients content were affected when compared to the control. From the work potassium level experienced a significant increase as Ultrasound time increases. also, there is a decline in Potassium level as the Blanching time increased. It was observed that there is an increase in Iron content as the Ultrasound time increased. Furthermore, it was observed that the Vitamin C level experienced a significant decrease as blanching time increased.

References

Chávez-Pesqueira, M., and Núñez-Farfán, J. (2017). Domestication and genetics of papaya: a review. Frontiers in Ecology and Evolution, 5, 155.

Chukwuka, K. S., Iwuagwu, M., and Uka, U. N. (2013). Evaluation of nutritional components of Carica papaya L. at different stages of ripening. *IOSR Journal of Pharmacy and Biological Sciences, 6(4), 13-16.*

Edomma Nelson Ekanem, Akindele Folarin Alonge, Elijah George Ikrang, Inimfon Samuel Ossom (2020**)** Optimization of Mechanically Expressed Coconut (Cocos Nucifera L.) Oil using Response Surface Methodology Inter. J. of Engineering and Science (IJES)vol. 9 Issue 6 Series 1 Pp 1-9, ISSN (e)2319-1813 ISSN(p) 20-24-1805

Fakayode, O. A., and Ajav, E. A. (2016). Process optimization of mechanical oil expression from Moringa (Moringa oleifera) seeds. *Industrial Crops and Products*, *90*, 142-151.

Haghi, A. K., and Amanifard, N. (2008). Analysis of heat and mass transfer during microwave drying of food products. *Brazilian Journal of Chemical Engineering*, 25, 491-501.

Heywood, V.H.; Brummitt, R.K.; Culham, A.; Seberg, O. (2007). Flowering plant families of the world. Firefly Books. ISBN 9781554072064.

Hussain, S. M., Sohrab, M. H., Al-Mahmood, A. K., Shuayb, M., Al-Mansur, M., and Hasan, C.

(2017). Clinical use of Carica papaya leaf extract in chemotherapy induced

thrombocytopaenia. *Int. J. Clin. Exp. Med*, 10, 3752-3756.

Ikrang, E. G., and Umani, K. C. (2019). Optimization of process conditions for drying of catfish (Clarias gariepinus) using response surface methodology (RSM). *Food science and human wellness,* 8(1), 46-52.

Kumar, A., Koul, B., Pudhuvai, B., Sharma, C., Sharma, V., Yadav, D., and Jin, J. O. (2022). Carica papaya L.: a tropical fruit with benefits beyond the tropics. Diversity, 14(8), 683.

Mahmood, A. A., Sidik, K., and Salmah, I. (2005). Wound healing activity of Carica papaya L. aqueous leaf extract in rats. *International Journal of Molecular Medicine and Advance Sciences,* 1(4), 398-401.

Minh, N. P., Nhi, T. T. Y., Lam, T. D. B., Nhat, P. M., and Phuong, N. T. T. (2019). Effect of blanching and drying on quality of dried papaya fruit. *Journal of Pharmaceutical Sciences and Research*, 11(3), 1082-1086.

Osunde, Z. D. (2017). Effect of pretreatments and drying methods on some qualities of dried mango (Mangifera indica) fruit. *Agricultural Engineering International: CIGR Journal*, 19(1), 187-194

Ronse De Craene, L.P. (2010). Floral diagrams: an aid to understanding flower morphology and evolution. Cambridge*: Cambridge University Press*. ISBN 978-0-521-49346-8.

Saeed, F., Arshad, M. U., Pasha, I., Naz, R., Batool, R., Khan, A. A and Shafique, B. (2014). Nutritional and phyto-therapeutic potential of papaya (Carica papaya Linn.): an overview. *International Journal of Food Properties*, 17(7), 1637-1653.

Saliasi, I., Llodra, J. C., Bravo, M., Tramini, P., Dussart, C., Viennot, S., and Carrouel, F. (2018). Effect of a toothpaste/mouthwash containing Carica papaya leaf extract on interdental gingival bleeding: a randomized controlled trial. International *Journal of Environmental Research and Public Health*, 15(12), 2660.

Sharmeen, R., Hossain, M. N., Rahman, M. M., Foysal, M. J., and Miah, M. F. (2012). In-vitro antibacterial activity of herbal aqueous extract against multi-drug resistant Klebsiella sp. isolated from human clinical samples. *International Current Pharmaceutical Journal*, 1(6), 133-137.

Vyas, M. B., and Shah, S. K. (2016). Review on nutritional and medicinal values of â€ œCarica papayaâ€. *Journal of Pharmacognosy and Phytochemistry*, 5(4), 284-286.

Effects of Temperature and Solid-liquid-ratio on the Extraction of Total Phenolic Content of Hibiscus sabdariffa leaves

Akpan, M. G[a]; Ikrang, E. G[a]. , Alonge, A. F[a]; & Jerome, I. T[a]

a Department of Agricultural and Food Engineering, Faculty of Engineering, University of Uyo. Nigeria

*Correspondence: mfrekemfongakpan@uniuyo.edu.ng

Abstract

Hibiscus sabdariffa leaves (HSL) can be used as tea leaves because of its bioactive compounds. This study demonstrates the effects of extraction temperature and solid liquid extraction ratio on the total phenolic content (TPC) of HSL. The HSL was harvested, washed dried with vacuum dryer at 40 °C and ground. The resultant powder was characterized in terms of tapped and bulk density, Carr's index and Hausner ratio to ascertain its flow characteristics prior to the extraction using distilled water as the extraction medium at 70, 80and 90 °C and at the solid-liquid ratio of 1:9 and 3:7. The bulk and tapped density of 212m were 20.29 ± 0.1753 g/ml and 25.58 ± 0.2700 g/ml respectively .The carr index and Hausner ratio were 20.67 ± 1.154 and 1.26 ± 0.0185 respectively. Maximum extraction TPC was observed at 90 °C and at the solid-liquid ratio of 1:9 while the least TPC was observed at 70° C at 3:7 solid-liquid ratio.

Introduction

Hibiscus sabdariffa is a plant of Malvaceae family, a blooming shrub found mostly in the tropical regions of Africa and Asia (Edo et al., 2023). The English name for this plant is Roselle while Nigerians call it Zobo. The leaves and calyx are the most commonly used parts of the plant for culinary and medicinal purposes (Agunbiade et al., 2022). Its Culinary use include as ingredient in soups, stews, cakes, wine, drinks, jams, pudding, tea etcetera while medicinally, the plant is believed to poses abilities to manage a plethora of diseases ranging from age related to degenerative diseases such as cancer, diabetes, high blood pressure etcetera. Teas are mostly made from plants parts to extract bioactive compounds such as polyphenols for use in the human body as it enhances many human physiological functions. The plant's therapeutic uses have been documented in (Riaz & Chopra, 2018). Roselle leaves potentials for use for medicinal purposes are due to its high content of polyphenols.

Polyphenols are naturally found bioactive compounds in plants' parts such as leaves, flowers, fruits and seeds. Polyphenols are secondary metabolites and a broad group of bioactive compounds with high antioxidant effects (Chen et al., 2024) . Polyphenols are primarily responsible for the healing capabilities of most plant parts the reason they are used in supplements due to their bioactivities (Feng & Zhang, 2023; Sahraeian et al., 2023). As consumers' choices and lifestyle shift towards healthy choices, this study presents the effects of temperature and solid-liquid ratio on the extraction of total phenolic content of Hibiscus sabdariffa leaves.

Material and Methods

The Hibiscus Sabdariffa leaves used for this experiment were harvested form the experimental farm of the Agricultural and Food Engineering University of Uyo, Nigeria. They were processed and dried as described in (Oladejo et al., 2023) with some modifications. Briefly, they were harvested, washed and dried using vacuum dryer oven at 40 °C and record of the mass every 15 minutes until constant mass was obtained. The resulting dried leaves were ground to powder and used for the experiments.

Determination of flow properties

Bulk and tapped densities, Carr's index and Hausner ratio were the flow properties that were determined to characterize the powder sample.

Bulk and tapped density

The tapped density of zobo was determined by hitting a 500ml cylinder filled with zobo leaves powder to the 500 ml level mark. The initial mass was read before tapping 200 times. Bulk density was determined with the initial mass and volume before tapping. Tapped and bulk density was calculated using Equation 1.

$$Density = \frac{Mass}{Volume} \quad (1)$$

Carr's index and Hausner ratio determinaton

Carr's index and Hausner ratio were derived from the bulk density (ρ_{bulk}) and tapped density (ρ_{tapped}) values of zobo powder using the following Equations 2 and 3 (Carr, 1965; Hausner, 1967)

$$Carr's\ Index = 1 - \frac{\rho_{bulk}}{\rho_{tapped}} \times 100 \quad (2)$$

$$Hausner\ ratio = \frac{\rho_{bulk}}{\rho_{tapped}} \quad (3)$$

Where ρ_{bulk} and ρ_{tapped} are bulk and tapped densities respectively.

Determination of moisture content

Moisture content was determined as found in (Akpan et al., 2021)**.** Five grams (5g) of the sample was placed in an oven at 105 ^{0}C for 24 hours.On cooling, the sample was weighed again and the weight loss recorded. The moisturecontent was calculated using Equation 4

$$Moisture\ Content = \frac{M_1 - M_2}{M_1} \times 100 \quad (4)$$

Where; M1 = initial mass of the ground sample, M_2 = Mass of dried sample.

Extraction

Distilled water was used as the extraction liquid for total phenols from Roselle (Hibiscus sabdariffa) leaves at temperatures of 70, 80 and 90°C and extraction time of 150min readings were taken at15 mins intervals. Two solid-liquid ratios were used for extraction: 1:9 and 3: 7. For 1:9 extraction procedure, 10 milligrams of ground sample was measured and placed in a 500 ml cylindrical beaker and 90 ml of distilled water was added and placed on a magnetic stirrer at level 5 stirring magnitude to extractfor 15 min interval till 105 mins. The same procedure was done for 70ml of distilled water and 30 milligram of sample (7:3 liquid-solid ratio). Each experiment was done in triplicate.

Determination of Total Polyphenol Content

The analysis of total phenolic content was carried out as described by (Chen et al., 2024).
1 ml sample solution was mixed with 4 ml sodium carbonate solution (75 g/l) in a 10 ml measuring flask. The flask containing the mixture was shaken vigorously. A 2 ml solution of folinciocalteu reagent was then added into the measuring flask and the mixture was shaken. Distilled water was continuously added until homogeneity was obtained. This mixture was left in a dark room at room temperature for one hour. The absorbance of the mixture was then measured at a wavelength of 760 nm using a UV-spectrophotometer. The total phenolic content was expressed as gallic acid equivalent in mg per gram of dry extract.

Results and Discussion

The bulk and trapped density of the Rosella leaves at 212 µm particle size were 20.29 ± 0.1753and 25.58 ± 0.2700 respectively .The car index and Hausner ratio at 212µm were 20.67 ± 1.154 and 1.26 ± 0.0185 respectively.

Effect of Temperature on yield of total phenolic content of Roselle leaves

Extraction temperature played a major role in the extraction of total phenolic content (TPC) in Roselle leaves. Increase in the extraction temperature of distilled water and extraction time increased the amount of total phenolic content extracted from Roselle leaves. The maximum concentration of phenol was obtained at extraction temperature 0f 90°C and extraction time of 150min. This trend was observed at all solid-liquid ratios studied (Figures 1& 2).

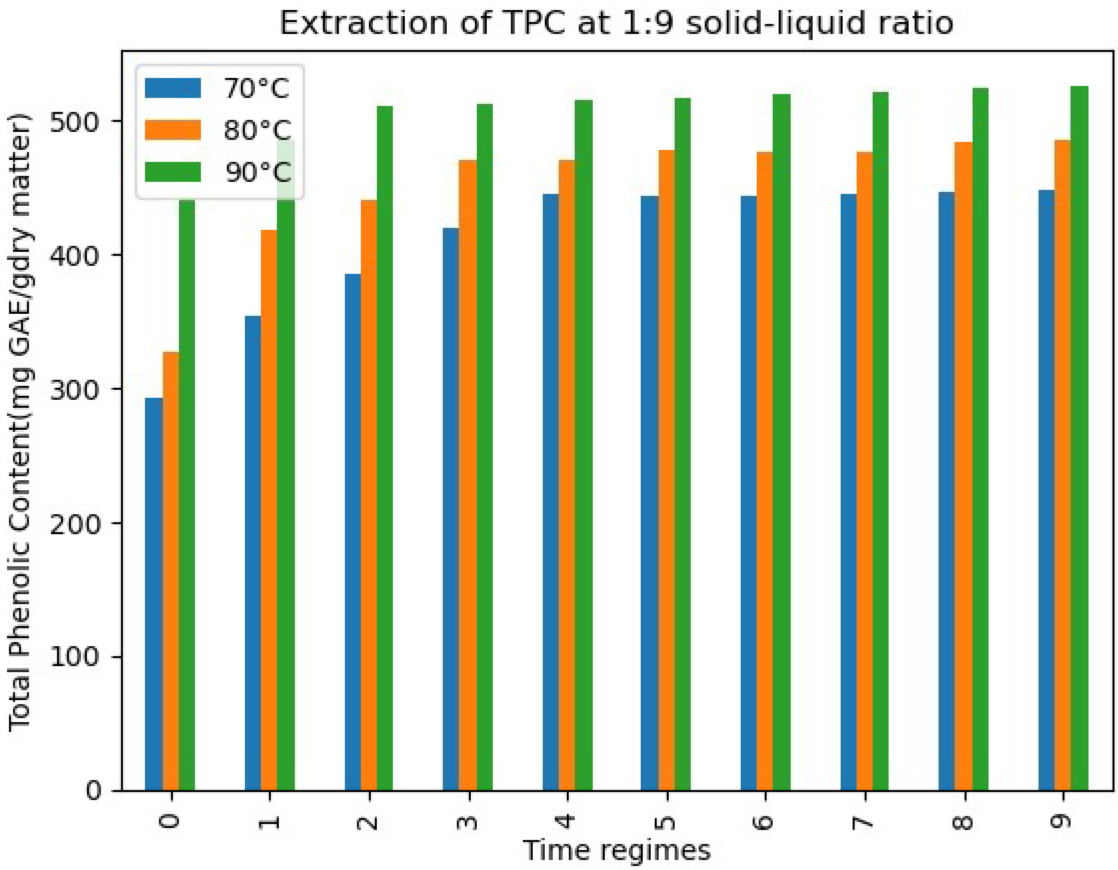


Figure 1: Extraction of TPC (mgGAE/gdry matter) at 1:9 solid-liquid ratio for time regimes of 0=15 mins, 1=30 mins, 2=45 mins, …….9= 150 mins.

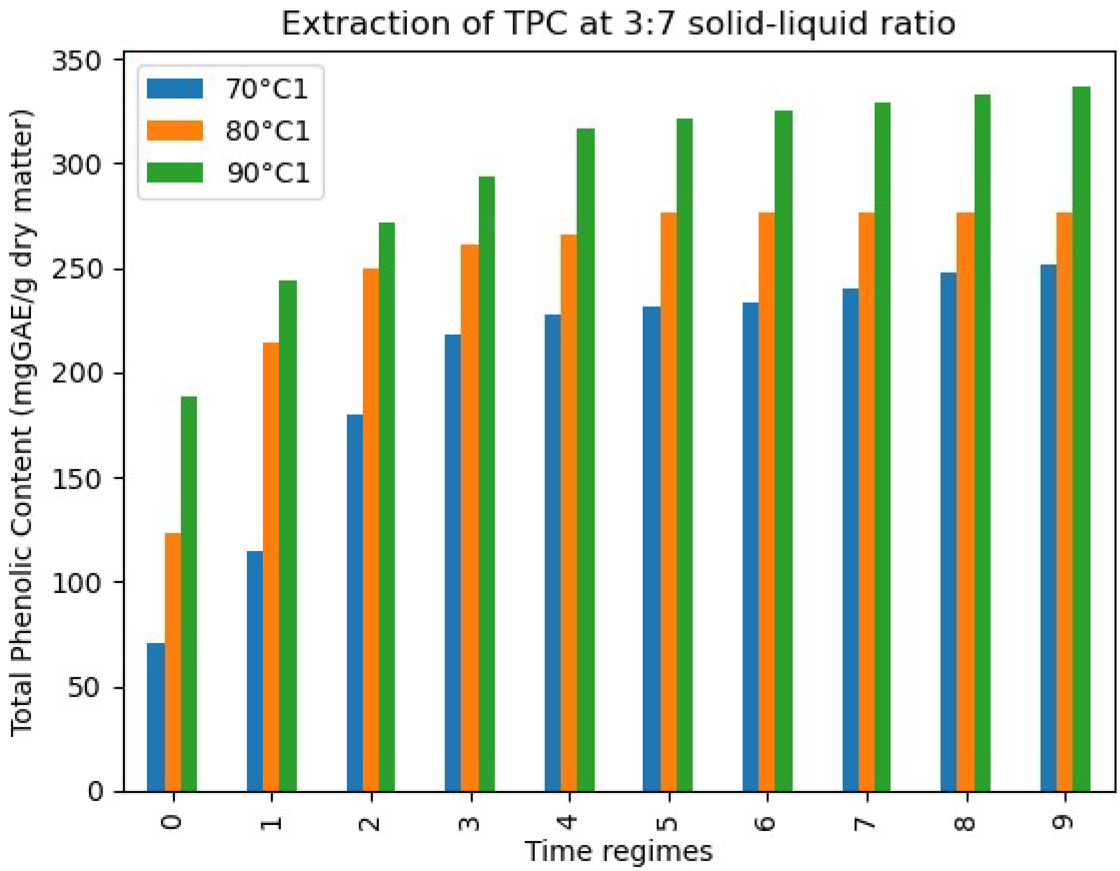


Figure 2: Extraction of TPC (mgGAE/gdry matter) at 3:7 solid-liquid ratio for time regimes of 0=15 mins, 1=30 mins, 2=45 mins, …….9= 150 mins.

Figures 1 and 2 show the extraction of TPC from Roselle leaves at the solid-liquid ratio of 1:9 and 3:7 at time regimes of 0-9 corresponding to 15 mins – 150 mins (at 15 mins increment). At every time regime, an increase in temperature resulted in an increase in the TPC extracted. The minimum TPC was obtained at 70 °C for both solid-liquid ratios and the maximum TPC was obtained at 90 °C this is due to the consequent increase of the diffusion rate and solubility of the extracted substances. Additionally, Roselle being rich in vitamin C doesn't degrade its anthocynins at high temperature as Vitamin C as an inhibitor, though other fractions of TPC may degrade, the rate of degradation is lower than the rate of production (Fiacre et al., 2023). The effect of time on the TPC yield as seen in Figures 1 and 2 is due to the accumulation of the TPC over time and the continuous embrittlement of the leaves particles over time to release the polyphenols.

Table 1: Effect of Solid-Liquid ratio on the distil water extraction of TPC of Roselle Leaves.

	Time	70°C	80°C	90°C	70°C1	80°C1	90°C1
count	10.000000	10.000000	10.000000	10.000000	10.000000	10.000000	10.000000
mean	82.500000	412.167220	452.748650	506.848970	201.627954	249.790630	296.116720
std	45.414755	53.055021	48.878707	26.221054	61.465468	48.576150	48.058401
min	15.000000	292.072900	327.532300	439.820700	70.980440	123.286500	188.815900
25%	48.750000	393.464800	447.762125	510.801250	189.587275	252.288375	277.596550
50%	82.500000	443.760600	473.802750	515.787700	229.882000	271.388900	319.066700
75%	116.250000	444.991850	477.681100	520.774225	238.256875	276.531300	327.992550
max	150.000000	448.193100	484.883800	525.760700	251.259900	276.678300	336.918400

Footnotes: 70°C, 8°0 and 9°0 are for the extraction at 1:9 solid-liquid extraction while 70° C1, 80 °C1 and 90° C1 are for the extraction at 3:7 solid-liquid extraction

Total phenolic content was observed to decrease when the solid-liquid content was increased as shown in Table 1. This is contrary to the observation of (Fiacre et al., 2023). Table 1 shows the mean, standard deviation, minimum values (at 15 minutes) , IQR and the maximum values for all the temperature run of this experiment and for the the two solid-liquid ratios studied. Maximum values were obtained with the extraction ratio of 1:9 solid-liquid at 90 °C (525.76 mg GAE/g dry matter). This can be explained with saturation of solutes in solution.

Conclusion

This study evaluated the effects of process parameters like the solid-liquid ratio, temeparature and time on the yield of total polyphenol content (TPC) of Hibiscus sabdariffa leaves. The temperatures used were 70, 80 and 90° C , solid-liquid ratio of 1:9 and 3:7 were used for time of 15, 30, 45, 60, 75, 90, 105, 120, 135 and 150min. It was observed that Temperature was an important factor during the process: 90 °C had the highest TPC at both Solid-liquid ratios (525.76mgGAE/g dry matter and 336.92 mgGAE/g dry matter for 1:9 and 3:7 solid liquid ratios respectively. The least TPC was observed at 70 °C at 15 mins for both Solid-liquid extraction ratios. This was due to the high solubility rate at high temperature and the higher rate of generation of phenolic compounds than the degradation rate. Increase in Solid-liquid ratio adversely affected the extraction of TPC of Roselle leaves.

Acknowledgement

This work was supported with grant no: TETFund/DR&D/CE/NRF/STI/14/VOL1; from TETFUND

References

Agunbiade, H. O., Fagbemi, T. N., & Aderinola, T. A. (2022). Antioxidant properties of beverages from graded mixture of green/roasted coffee and hibiscus sabdariffa calyx flours. *Applied Food Research*, *2*(2), 100163. https://doi.org/10.1016/j.afres.2022.100163

Akpan, M. G., Assian, U. E., & Ikrang, E. G. (2021). Effects of pretreatment and drying temperature on antioxidants and antinutrients of Justicia insularis and Jatropha tanjorensis leaves. *Poljoprivredna Tehnika*, *46*(3), 74–88.

Carr, R. L. (1965). Evaluating flow properties of solids. *Chemical Engineering*, *72*, 163–168.

Chen, J., Chen, X., Zhang, Y., Feng, Z., Zhu, K., Xu, F., & Gu, C. (2024). Bioactivity and influence on colonic microbiota of polyphenols from noni (Morinda citrifolia L.) fruit under simulated gastrointestinal digestion. *Food Chemistry: X*, *21*, 101076. https://doi.org/10.1016/j.fochx.2023.101076

Edo, G. I., Samuel, P. O., Jikah, A. N., Oloni, G. O., Ifejika, M. N., Oghenegueke, O., Ossai, S., Ajokpaoghene, M. O., Asaah, E. U., Uloho, P. O., Akpoghelie, P. O., Ugbune, U., Ezekiel, G. O., Onoharigho, F. O., Agbo, J. J., & Essaghah, A. E. A. (2023). Proximate composition and health benefit of Roselle leaf (Hibiscus sabdariffa). Insight on food and health benefits. *Food Chemistry Advances*, *3*, 100437. https://doi.org/10.1016/j.focha.2023.100437

Feng, J., & Zhang, Y. (2023). The potential benefits of polyphenols for corneal diseases. *Biomedicine & Pharmacotherapy*, *169*, 115862.

Fiacre, K., Mohammed, M. A., & Carly, D. Z. S. (2023). Extracting juice from dates (Phoenix dactylifera L.) using response surface methodology: Effect on pH, vitamin c, titratable acidity, free amino nitrogen (FAN) and polyphenols.: Optimization of date juice extraction process from" Bournow" cultivar: Effects of temperature, time, volume/mass ratio, and enzyme volume on Bioactive Compounds (proposed title reviewer2). *Applied Food Research*, 100375.

Hausner, H. H. (1967). *Friction conditions in a mass of metal powder.* Polytechnic Inst. of Brooklyn. Univ. of California, Los Angeles.

Oladejo, A. O., Nkem, O. M., Alonge, A. F., Akpan, M. G., Etti, C. J., Okoko, J. U., & Etuk, N. (2023). Influence of ultrasound-pretreated convective drying of Roselle (Hibiscus sabdariffa L) leaves on its drying kinetics and nutritional quality. *Scientific African*, *20*, e01704. https://doi.org/10.1016/j.sciaf.2023.e01704

Riaz, G., & Chopra, R. (2018). A review on phytochemistry and therapeutic uses of Hibiscus sabdariffa L. *Biomedicine & Pharmacotherapy*, *102*, 575–586. https://doi.org/10.1016/j.biopha.2018.03.023

Sahraeian, S., Rashidinejad, A., & Golmakani, M.-T. (2023). Recent advances in the conjugation approaches for enhancing the bioavailability of polyphenols. *Food Hydrocolloids*, 109221.

Dijital Teknolojiler ile Entegre Edilmiş Akıllı Kurutma Sistemleri: Yeni Nesil Uygulamalar

[1]Fatma Ebrar Öztürk, [1]Hande Baltacıoğlu, [1,*]Cem Baltacıoğlu, [1,]Mehmet Yetişen, [1]Hasan Uslu

[1]Ömer Halisdemir Üniversitesi Mühendislik Fakültesi Gıda Mühendisliği Bölümü
*Sorumlu yazar: cembaltacioglu@ohu.edu.tr

Özet

Gıdalar, dış etkenlerden çok çabuk bozulmaktadır ve bol oldukları mevsimde tamamen tüketilemezler, bunun için gıdaları uzun süre saklamaya yönelik çalışmalarda birçok yöntem geliştirilmiştir. Bu yöntemler arasında en eski ve ekonomik olanı kurutmadır. Kurutma işlemi, gıdanın içerisindeki suyun uzaklaştırılmasıyla mikrobiyal faaliyetlerin ve kimyasal reaksiyonların yavaşlatılmasını sağlar. Geleneksel güneş altında kurutma, her bölgede uygulanabilir olmadığı gibi hijyenik açıdan da sınırlıdır. Bu nedenle kontrollü koşullarda çalışan yapay kurutma sistemleri geliştirilmiştir. Modern kurutma teknikleri, doğal yöntemlere kıyasla daha kaliteli ve dayanıklı ürünler sunmaktadır. Bu çalışmada, gıda endüstrisinde kullanılan kurutma yöntemleri ve bu sistemlerin temel özellikleri ele alınmıştır.

***Anahtar kelimeler**: Kurutma, gıda kurutma sistemleri, dehidrasyon, rehidrasyon, kurutucular*

Giriş

Kurutma, bozulma yapan mikroorganizmaların gelişimlerini azaltmak ve kimyasal reaksiyonların oluşmasını engellemek için gıdalardan suyun uzaklaştırıldığı bir süreçtir (Vega Mercado ve ark., 2001). Kurutma sözcüğü, ham, yarı işlenmiş ya da işlenmiş katı, sıvı ve yarı sıvı gıdaların yapılarındaki su oranının azaltılarak belirli düzeylere düşürülme işlemini tanımlamaktadır (Saldamlı & Saldamlı, 2004). Kurutma, yalnızca gıdanın raf ömrünü uzatmakla kalmaz; aynı zamanda ürünün taşınmasını ve depolanmasını kolaylaştırır, hacmini küçültür ve kullanım sırasında yüksek rehidrasyon kapasitesine sahip ürünler elde edilmesini sağlar.
Uygun kurutma koşullarının seçilmemesi, gıdanın rengi, aroması, dokusu, besin değeri ve depolama stabilitesi üzerinde olumsuz etkiler yaratabilir. Bu nedenle kurutma sistemlerinin tasarımında ürün özellikleri, hedeflenen kalite kriterleri ve enerji verimliliği dikkate alınmalıdır. Sonuç olarak, en az kalite kaybıyla en yüksek kurutma verimini sağlayan, ekonomik ve sürdürülebilir teknolojilerin tercih edilmesi esastır. Bu doğrultuda çeşitli tiplerde kurutucular geliştirilmiş ve gıda endüstrisinde yaygın olarak kullanılmaya başlanmıştır (Farral, 1976).
Gıdalardan nemin uzaklaştırılmasında kullanılan kurutucular, ısının ürüne aktarılma yöntemine göre sınıflandırılır. Temel olarak konveksiyonel sıcak hava kurutucuları, vakum kurutucuları, mikrodalga ve radyo frekans kurutucuları, dondurarak kurutma sistemleri ve hibrit teknolojiler olmak üzere farklı tipleri mevcuttur (Saldamlı & Saldamlı 2004). Her sistemin kendine özgü avantajları ve sınırlamaları bulunur.

Konveksiyonel (Sıcak Hava) Kurutucular

Bu grupta yer alan fırın, kabin, tünel, bantlı, sandık ve püskürtmeli kurutucular, sıcak havanın ürüne temas etmesiyle nemin buharlaştırılmasını sağlar.
Fırın Kurutucular: En basit yapıya sahip olup, ürün sıcak hava ile temas ettirilerek kurutulur. Genellikle meyve dilimlerinde tercih edilir.
Kabin Kurutucular: Tepsiler üzerinde sabit duran ürünler, sıcak hava akımıyla kurur. Çok yönlü olmaları ve farklı ürünlere kolay uyarlanabilmeleri nedeniyle yaygın kullanılır.
Tünel Kurutucular: Ürünler hareketli vagonlar üzerinde kurutma odasından geçirilir. Sürekli çalışabilen bu sistem, yüksek kapasiteli kurutma için uygundur.
Bantlı Kurutucular: Ürünler konveyör bant üzerinde taşınarak kurutulur. İki aşamalı kurutma sağlayan bu sistem, homojen kurutma verimi sunar.
Sandık Kurutucular: Kurutmanın son aşamasında nemin %3-6 seviyesine indirilmesinde kullanılır. Uzun süreli işlem gerektirir.
Püskürtmeli Kurutucular: Sıvı veya yarı sıvı ürünlerin damlacık haline getirilip sıcak hava ile hızla kurutulmasını sağlar. Süt tozu, bebek maması ve meyve tozları gibi ürünlerin üretiminde yaygındır.

Vakum Kurutucular

Vakum kurutucular ısıya duyarlı ürünlerin, vakum altında daha düşük sıcaklıklarda hızla kurumasını sağlamak amacıyla geliştirilmişlerdir. Atmosferik koşullarda kurutma yöntemleri ile karşılaştırıldığında, vakumlu kurutma yöntemi; daha düşük kurutma sıcaklığı ve oksijensiz ortamda kuruma gibi bazı karakteristik özelliklere sahip olup, daha kaliteli ürün elde edilmesini sağlamaktadır. (Şahin ve ark., 2012). Ortamda hava olmadığı için oksidasyon da yoktur. Renk, kolaylıkla okside olabilen vitaminler ve çözünmeyen yağlar korunabilmektedir. Düşük sıcaklık derecelerinde çalışıldığı için aroma bozuklukları da en aza indirilir. Nem, iç yüzeylerden daha kolay uzaklaştırılabilmektedir ve vakum koşulları ürüne puf yapı kazandırmaktadır.

Pnömatik ve Döner Kurutucular
Pnömatik kurutucularda küçük partiküller sıcak hava akımıyla dikey borularda taşınarak kurutulur. Döner kurutucular ise ürünün yavaşça dönen bir silindir boyunca taşındığı sistemlerdir. Kısa temas süreleri sayesinde ürün fazla ısınmadan kurur.

Hibrit Sistemler
Günümüzde püskürtmeli-bant, akışkan yataklı, kırınım pencereli ve ısı pompalı kurutucular gibi hibrit teknolojiler geliştirilmiştir. Bu sistemler, farklı kurutma mekanizmalarını birleştirerek hem enerji verimliliği hem de ürün kalitesi açısından avantaj sunar.

Dondurarak Kurutma (Liyofilizasyon)
Dondurarak kurutma yöntemi olan liyofilizasyon, gıda endüstrisinde önemli bir yer tutar. Bu yöntemde, ürün önce dondurularak katı hale getirilir ve daha sonra düşük basınç altında buz doğrudan buhar fazına geçer, bu süreç süblimasyon olarak adlandırılır. Literatürde yapılan çalışmalar, liyofilizasyonun aroma, renk ve besin değerinin korunmasında en etkili yöntemlerden biri olduğunu ortaya koymuştur (Ciurzyńska ve Lenart, 2011).
Liyofilizasyonun özellikle suda çözünür vitaminlerin ve minerallerin kaybını minimize ederken, ürünlerin rengini ve dokusunu da korur (Karagül & Altuntaş, 2018). Araştırmalar, liyofilizasyonun genellikle farmasötik endüstrisinde kullanıldığını, ancak son yıllarda gıda endüstrisinde de artan popülaritesine dikkat çekmektedir (Kırtıl & Öztop, 2014). Sonuç olarak, liyofilizasyon, gıda endüstrisindeki teknolojik ilerlemelerle birlikte, ürünlerin kalitesini artırmak ve pazarlanabilirliğini sağlamak için önemli bir yöntem olarak kabul edilmektedir.

Mikrodalga ve Radyo Frekans Kurutucuları
Bu teknolojiler, elektromanyetik dalgalarla ürünün içten ısınmasını sağlar. Geleneksel kurutmaya göre daha hızlıdır ve nem transferi daha etkindir. Radyo frekansı, daha homojen ısınma avantajı sunar.

Özel Teknikler: Puf ve Köpük Kurutma
Puf kurutma, ürünün ani basınç değişimiyle süngerimsi bir yapı kazanmasını sağlar. Köpük kurutma ise sıvı gıdalarda yüzey alanını artırarak suyun hızlı uzaklaşmasına olanak verir. Her iki yöntem de kurutma süresini kısaltırken ürün kalitesini korur.

Özgünleştirilmiş Yeni Nesil ve Dijital Teknolojilerle Entegre Kurutma Sistemleri
Kurutma teknolojisindeki son gelişmeler hem enerji verimliliğini artırmak hem de gıda kalitesini korumak amacıyla hibrit ve akıllı sistemlerin geliştirilmesine odaklanmıştır. Geleneksel yöntemlerin sınırlamalarını ortadan kaldırmak için güneş enerjili, kızılötesi, kırınım pencereli ve ısı pompalı sistemler gibi yenilikçi teknolojiler kullanılmaktadır. Ayrıca dijital kontrol üniteleri, sensörler ve yapay zekâ destekli algoritmalar sayesinde kurutma süreci gerçek zamanlı olarak izlenebilmekte ve optimize edilmektedir.

Güneş Enerjili Kurutma Sistemleri
Güneş enerjisi, kurutma işlemlerinde uzun süredir kullanılmakla birlikte, modern tasarımlar bu yöntemi daha verimli ve hijyenik hale getirmiştir. Doğrudan güneş ışığıyla yapılan kurutmada sıcaklık kontrolü zordur ve ürün kalitesi değişkenlik gösterir. Bu nedenle sera tipi, zorlanmış taşınımlı veya panel destekli sistemler geliştirilmiştir (Shanmugam ve Natarajan, 2006). Bu teknolojiler, enerji maliyetini azaltırken özellikle kırsal bölgelerde sürdürülebilir bir çözüm sunar.

Isı Pompalı Kurutma Sistemleri
Isı pompalı kurutma, düşük enerji tüketimi ve gelişmiş ısı geri kazanımı sayesinde yüksek verimliliğe sahip bir teknolojidir. Kurutma sırasında sıcaklık hassasiyetinin yüksek olduğu gıdalarda, kalite kaybı minimum seviyede tutulur. Bu sistemler aynı zamanda daha kontrollü nem ve sıcaklık profili sağlar, ancak ilk yatırım maliyetleri yüksektir (Chou ve Chua, 2001).

Kızılötesi (IR) Kurutma
Kızılötesi enerji, çevredeki havayı ısıtmadan doğrudan ürün yüzeyine ısı transfer eder. Yüksek ısı transfer oranları ve kompakt tasarımı sayesinde hızlı ve etkili kurutma sağlar. Ayrıca mevcut kurutuculara entegre edilerek ek ısı kaynağı olarak kullanılabilir. Bu teknoloji, özellikle yüzey kurutmasında oldukça avantajlıdır.

Kırınım Pencereli Kurutma
Bu sistemde, ürünün üzerine konan özel bir membran sayesinde ısı transferi yalnızca gerekli olduğunda gerçekleşir. Ürün üzerindeki nem bu membranı geçirgen hale getirir ve ısı transferi sağlanır; nem azaldığında ise

ısı yansıması geri döner. Böylece enerji kayıpları minimize edilirken ürünün rengi, besin değeri ve antioksidan kapasitesi korunur (Tontul ve ark., 2019).

Dijital Teknolojiler ve Akıllı Kontrol Sistemleri

Yeni nesil kurutma sistemleri, sıcaklık, nem ve hava akışı gibi parametreleri sürekli izleyen sensörlerle donatılmıştır. Bu sensörlerden alınan veriler, yapay zekâ ve otomasyon yazılımları aracılığıyla analiz edilerek kurutma süreci gerçek zamanlı optimize edilir. Böylece hem enerji tüketimi azalır hem de ürün kalitesi standart hale getirilir. Endüstri 4.0 uygulamalarıyla entegre çalışan bu sistemler, gıda üretiminde yüksek verimliliğin yanında sürdürülebilirlik hedeflerine de katkı sağlar.

Kurutma, gıda endüstrisinde hem raf ömrünü uzatmak hem de taşıma ve depolama maliyetlerini azaltmak amacıyla yaygın olarak kullanılan bir yöntemdir. Ancak, yanlış seçilen kurutma koşulları ürün kalitesinde ciddi kayıplara yol açabilir. Bu nedenle, kurutma işleminin tasarımında ürünün ısıl duyarlılığı, hedeflenen nem oranı ve enerji tüketimi gibi parametrelerin dikkatle belirlenmesi gerekmektedir.

Klasik sıcak hava kurutucuları düşük yatırım maliyetleri nedeniyle halen kullanılmakla birlikte, homojen kurutma sağlama konusunda yetersiz kalabilirler. Bu durum, ürün yüzeylerinde düzensiz nem dağılımı ve kalite kayıplarıyla sonuçlanmaktadır. Bu sorunu çözmek için hibrit ve yeni nesil sistemlerin tercih edilmesi önerilmektedir.

Mikrodalga, radyo frekans ve kızılötesi gibi modern teknolojiler, ürün içinde daha eşit ısı dağılımı sağlayarak kurutma süresini kısaltır. Bununla birlikte, bu teknolojilerin enerji verimliliği yüksek olsa da yatırım maliyetlerinin yüksek olması yaygın kullanımını sınırlamaktadır. Dondurarak kurutma yöntemi ise üstün kalite sağlamasına rağmen hem işlem süresi hem de maliyet açısından dezavantajlıdır. Son yıllarda dijitalleşme ve yapay zekâ destekli kontrol sistemlerinin devreye girmesi, kurutma teknolojilerinde önemli bir dönüşüm yaratmıştır. Sensör destekli izleme sistemleri ve otomatik ayarlamalar sayesinde kurutma süreci gerçek zamanlı optimize edilmekte, böylece hem enerji tasarrufu sağlanmakta hem de ürün kalitesi iyileştirilmektedir.

Sonuç

Bu çalışmada, gıda endüstrisinde kullanılan geleneksel ve modern kurutma sistemleri incelenmiş, her bir yöntemin avantajları ve sınırlamaları değerlendirilmiştir. Sonuç olarak, kurutma teknolojilerinin seçiminde tek bir yöntemin her ürün için uygun olmadığı; ürün özellikleri, enerji tüketimi, yatırım maliyeti ve kalite hedeflerinin birlikte göz önünde bulundurulması gerektiği anlaşılmıştır. Gelecekte, dijital teknolojilerle entegre edilen akıllı kurutma sistemlerinin daha yaygın kullanılacağı ve bu sistemlerin hem kaliteyi koruyarak hem de enerji verimliliğini artırarak endüstriyel uygulamalarda ön plana çıkacağı öngörülmektedir. Ayrıca sürdürülebilirlik açısından, yenilenebilir enerji kaynaklarının ve düşük maliyetli hibrit çözümlerin öneminin giderek artacağı düşünülmektedir.

Kaynaklar

Chou, S. K., & Chua, K. J. (2001). New hybrid drying technologies for heat sensitive foodstuffs. *Trends in Food Science & Technology*, *12*(10), 359–369. https://doi.org/10.1016/S0924-2244(01)00102-9

Ciurzyńska, A., & Lenart, A. (2011). Freeze-drying – application in food processing and biotechnology – a review. *Polish Journal of Food and Nutrition Sciences*, *61*(3), 165–171.

Farrall, A. W. (Ed.). (1976). Food engineering systems. *Vol. 1. Operations* (pp. x+-615pp).

Karagül, M. S., & Altuntaş, B. (2018). Liyofilizasyon: genel proses değerlendirmesi. *Etlik Veteriner Mikrobiyoloji Dergisi*, *29*(1), 62-69. https://doi.org/10.35864/evmd.513002

Kırtıl, E., & Öztop, M. H. (2014). Enkapsülasyon maddesi olarak lipozom ve gıdalarda kullanımı: Yapısı, karakterizasyonu, üretimi ve stabilitesi. *Akademik Gıda*, *12*(4), 41-57.

Şahin, F. H., Ülger, P., Aktaş, T., & Orak, H. H. (2012). Farklı önişlemlerin ve vakum kurutma yönteminin domatesin kuruma karakteristikleri ve kalite kriterleri üzerine etkisi. *Tekirdağ Ziraat Fakültesi Dergisi*, *9*(1), 15–25.

Saldamlı, İ., & Saldamlı, E. (2004). Gıda Endüstrisi Makinaları (2. Baskı). *Savaş Yayınevi*, Ankara.

Shanmugam, V., & Natarajan, E. (2006). Experimental investigation of forced convection and desiccant integrated solar dryer. *Renewable Energy*, *31*(8), 1239–1251. https://doi.org/10.1016/j.renene.2005.05.019

Tontul, İ., Eroğlu, E., & Topuz, A. (2019). Kırınım pencereli kurutma ve sıcak hava akımında kurutma işlem şartlarının kuşburnu tozlarının fizikokimyasal özellikleri üzerine etkisi. *Gıda*, *44*(1), 1–9. https://doi.org/10.15237/gida.GD18092

Endüstri 4.0 Işığında Kurutma Teknolojilerinin Dijital Dönüşümü

Sevde Kara Yiğit[1], Katibe Sinem Coruk[1], Hande Baltacıoğlu[1], Cem Baltacıoğlu[1]

[1]Gıda Mühendisliği Bölümü, Mühendislik Fakültesi, Niğde Ömer Halisdemir Üniversitesi, Niğde, Türkiye

Özet

Bu çalışma, Endüstri 4.0 teknolojilerinin kurutma sistemlerine entegrasyonunu ve bu entegrasyonun sağladığı avantajları kapsamlı bir şekilde incelemektedir. Siber-fiziksel sistemler (CPS), Nesnelerin İnterneti (IoT), yapay zeka (AI), büyük veri analitiği ve dijital ikiz teknolojilerinin kurutma süreçlerine uygulanması, enerji verimliliği, kalite kontrolü, izlenebilirlik ve sürdürülebilirlik açısından önemli iyileştirmeler sağlamaktadır. Çalışmada, geleneksel kurutma yöntemlerinin sınırlılıkları analiz edilmiş ve dijital dönüşümün bu sınırlılıkları nasıl aştığı detaylandırılmıştır. Türkiye'deki uygulama örnekleri ve sektörel deneyimler değerlendirilerek, dijital dönüşümün karşılaştığı zorluklar ve sağladığı faydalar objektif bir perspektifle sunulmuştur. Araştırma sonuçları, dijital teknolojilerin kurutma sistemlerinde %15-30 oranında enerji tasarrufu sağladığını ve ürün kalitesinde %10-20 oranında iyileşme meydana getirdiğini göstermektedir.

Anahtar Kelimeler: *Endüstri 4.0, kurutma teknolojileri, dijital dönüşüm, IoT, siber-fiziksel sistemler*

Giriş

Kurutma Teknolojilerinin Endüstriyel Önemi

Kurutma işlemi, gıda ve kimya endüstrilerinde ürün raf ömrünün uzatılması ve mikrobiyolojik bozulma riskinin minimize edilmesi amacıyla yaygın olarak kullanılan kritik bir işlem basamağıdır (Hassoun vd., 2025). Bu süreç, ürünlerin nem içeriğinin kontrollü bir şekilde azaltılması yoluyla gerçekleştirilmekte ve böylece ürünlerin taşınabilirliği artırılırken depolama ve nakliye maliyetleri önemli ölçüde düşürülmektedir. Ancak, geleneksel sıcak hava ile kurutma sistemlerinin yüksek enerji tüketimi, üretim maliyetleri açısından önemli bir dezavantaj oluşturmakta ve bu durum endüstriyel sürdürülebilirlik hedefleriyle çelişmektedir.

Endüstri 4.0 Paradigması ve Temel Bileşenleri

Endüstri 4.0, dijitalleşmenin dördüncü evrimsel aşaması olarak tanımlanmakta ve üretim süreçlerinin köklü bir dönüşümünü temsil etmektedir (Özdoğan, 2017). Bu paradigma, siber-fiziksel sistemler (CPS), Nesnelerin İnterneti (IoT), yapay zeka (AI), büyük veri analitiği ve dijital ikiz teknolojilerini entegre ederek üretim süreçlerine esneklik, otonomi ve interoperabilite kazandırmaktadır (Gürkan, 2021, Sarı, 2020). Bu teknolojik entegrasyon, bilgi akışının şeffaflaştırılması ve gerçek zamanlı karar alma mekanizmalarının geliştirilmesi yoluyla üretim verimliliğinin artırılmasını sağlamaktadır.

Kurutma Süreçlerinde Dijitalleşme Gerekliliği

Mevcut kurutma süreçleri, büyük ölçüde manuel kontrol mekanizmaları ve sabit otomasyon sistemleri ile yönetilmekte olup, bu yaklaşım enerji verimliliği ve ürün kalitesi açısından yetersiz kalmaktadır. Endüstri 4.0 teknolojilerinin devreye girmesiyle, IoT sensörleri aracılığıyla sıcaklık, nem ve enerji tüketimi parametrelerinin gerçek zamanlı izlenmesi mümkün hale gelmekte ve yapay zeka destekli analizler ile süreç optimizasyonu gerçekleştirilebilmektedir (Su vd., 2015).

Araştırmanın Amacı ve Kapsamı

Bu çalışmanın temel amacı, Endüstri 4.0 teknolojilerinin kurutma sistemlerine entegrasyonunu hem teorik hem de uygulamalı boyutlarıyla kapsamlı bir şekilde incelemektir. Araştırma kapsamında, dijital dönüşümün enerji verimliliği, kalite kontrolü, izlenebilirlik, sürdürülebilirlik ve üretim maliyetleri üzerindeki etkileri detaylı olarak analiz edilmektedir. Bu yaklaşım, literatürdeki mevcut boşlukları doldurmaya ve Türkiye'de uygulamalı pilot projeler için bilimsel bir temel oluşturmaya yönelik olarak tasarlanmıştır.

Kurutma Teknolojilerine Genel Bakış

Geleneksel Kurutma Yöntemleri ve Sınırlılıkları

Kurutma işlemleri tarihsel olarak güneş enerjisi ile kurutma, sıcak hava ile kurutma ve tamburlu (valsli) sistemler aracılığıyla gerçekleştirilmiştir. Güneş ile kurutma yöntemi, düşük işletme maliyeti avantajına sahip olmasına rağmen, kontrolsüz çevresel koşullar nedeniyle mikrobiyal kontaminasyon riski taşımakta ve ürün kalitesi üzerinde olumsuz etkiler doğurmaktadır (Kudra ve Mujumdar, 2009). Tamburlu kurutucularda ise sabit sıcaklık uygulaması ve düşük esneklik, özellikle yüksek nem içerikli ürünlerin homojen kurutulmasını zorlaştırmaktadır. Bu geleneksel yöntemler, maliyet avantajlarına karşın enerji verimliliği ve kalite kontrolü açısından önemli sınırlılıklar içermektedir.

Modern Kurutma Sistemleri ve Teknolojik Gelişmeler

Modern kurutma teknolojileri arasında vakumlu kurutma, dondurarak kurutma (liyofilizasyon) ve mikrodalga destekli kurutma sistemleri yer almaktadır (Kudra ve Mujumdar, 2009). Dondurarak kurutma yöntemi, ürünün organoleptik özelliklerini ve besin bileşenlerini koruyarak kaliteyi artırırken, mikrodalga kurutma işlem süresini kısaltarak üretim verimliliğini artırmaktadır. Bu teknolojiler, enerji tüketimi açısından daha verimli olmalarına rağmen, yatırım ve işletme maliyetleri açısından geleneksel sistemlere kıyasla daha yüksek finansal gereksinimler içermektedir.

Kurutma Süreçlerinde Enerji ve Kalite Parametreleri

Endüstriyel kurutma sistemlerinde enerji verimliliği, toplam üretim maliyeti ve çevresel etki açısından kritik öneme sahiptir. Yapılan araştırmalar, geleneksel sistemlerin tipik olarak %30-70 enerji verimliliği oranına sahip olduğunu ve ısı geri kazanım teknikleri ile bu oranın %40'lara kadar iyileştirilebileceğini göstermektedir (Kudra ve Mujumdar, 2009). Ürün kalitesi açısından, nem oranı, rehidrasyon kapasitesi, renk ve aroma gibi parametreler mikrodalga ve dondurarak kurutma sistemlerinde daha iyi korunmaktadır.

Endüstri 4.0'ın Temel Bileşenleri

Siber-Fiziksel Sistemler (CPS)

Siber-fiziksel sistemler, fiziksel süreçlerle yazılım sistemlerinin entegrasyonunu sağlayarak üretim hatlarının gerçek zamanlı izlenmesine ve merkezi olmayan kontrollü otomasyona olanak tanımaktadır (Ustundag ve Cevikcan, 2018). Bu sistemler, kurutma süreçlerinde fiziksel parametrelerin dijital ortamda modellenmesi ve kontrol edilmesi yoluyla süreç optimizasyonunu mümkün kılmaktadır.

Nesnelerin İnterneti (IoT) ve Sensör Teknolojileri

IoT teknolojisi, sensörler ve bağlı cihazlar aracılığıyla veri toplama, işleme ve iletme süreçlerini otomatikleştirmektedir. Bu sistem, makine ve proses performansının gerçek zamanlı değerlendirilmesini sağlayarak bakım ve müdahale gereksinimlerini önceden belirlemektedir (Hassoun vd., 2025). Kurutma sistemlerinde IoT uygulamaları, sıcaklık, nem, basınç ve enerji tüketimi gibi kritik parametrelerin sürekli izlenmesini mümkün kılmaktadır.

Büyük Veri ve Analitik Teknolojiler

Büyük veri teknolojileri, sensörlerden toplanan büyük hacimli verilerin işlenmesi ve üretim süreçlerinin optimizasyonu için kritik öneme sahiptir (Hassoun vd., 2025). Bu teknolojiler, kurutma süreçlerinde kalite sapmaları, arıza eğilimleri ve enerji tüketimindeki dalgalanmaların tahmin edilmesini sağlamaktadır.

Yapay Zeka ve Makine Öğrenmesi

Yapay zeka ve makine öğrenmesi teknolojileri, üretim süreçlerinde tahmine dayalı modelleme, hata tespiti ve kalite kontrol uygulamaları ile verimliliği artırmaktadır (Hassoun vd., 2025). Bu teknolojiler, CPS ve IoT kombinasyonunun çekirdeğini oluşturarak kurutma sistemlerinde otonom karar alma mekanizmalarının geliştirilmesini sağlamaktadır.

Dijital İkiz Teknolojisi

Dijital ikiz teknolojisi, fiziksel sistemlerin sanal kopyalarının oluşturulması yoluyla simülasyon, analiz ve sanal ortamda test yapma olanağı sağlamaktadır (Ustundag ve Cevikcan, 2018). Kurutma sistemlerinde dijital ikiz uygulamaları, sistem performansının önceden değerlendirilmesi ve optimizasyon stratejilerinin geliştirilmesi açısından önemli avantajlar sunmaktadır.

Kurutma Teknolojilerinde Dijital Dönüşüm

Akıllı Sensörler ve Endüstriyel IoT (IIoT)

Endüstri 4.0'ın temel bileşeni olan IIoT, kurutma sistemlerinde sıcaklık, nem, basınç ve enerji tüketimi gibi kritik parametrelerin gerçek zamanlı izlenmesini mümkün kılmaktadır (Hassoun vd., 2025, Fernando, 2024, Parente vd., 2023). Bu sistemlerde, sensörlerden elde edilen veriler merkezi bir kontrol birimine iletilerek anormallikler algılanabilmekte ve operatör veya otomasyon sistemine uyarı gönderilebilmektedir. Bu yaklaşım, süreç izlenebilirliği, kontrol doğruluğu ve sistem güvenilirliğini önemli ölçüde artırmaktadır.

Siber-Fiziksel Sistemler ve Otomasyon Entegrasyonu

Kurutma sistemlerinden toplanan gerçek zamanlı veriler, CPS yapılarında işlenerek dijital platforma aktarılmaktadır. Bu platformda işlenen veriler, sistemin kendini sürekli ayarlayabilmesi için geri besleme mekanizmalarını tetiklemektedir. Sıcaklık ve nem gibi parametreler tanımlı limitlerin dışına çıktığında, kontrol algoritmaları otomatik müdahalede bulunmaktadır. Bu model, geleneksel sistemlere kıyasla hem süreç kararlılığını hem de enerji verimliliğini yükseltmektedir (Ustundag ve Cevikcan, 2018).

Dijital İkiz Uygulamaları

Dijital ikiz teknolojisi, fiziksel kurutma cihazının birebir sanal modelini oluşturmaktadır (Ustundag ve Cevikcan, 2018). Bu yapı sayesinde sistem üzerinde yapılan her değişiklik; sıcaklık ayarı, nem seviyesi, hava akışı gibi parametreler simüle edilerek etkisi önceden değerlendirilebilmektedir. Dijital ikiz modeli sayesinde bakım maliyetlerinde azalma ve süreç optimizasyonunda artış elde edilmektedir.

Büyük Veri ve Yapay Zeka Entegrasyonu

Sensörlerden toplanan büyük veri, yapay zeka ve makine öğrenmesi teknikleri kullanılarak analiz edildiğinde, kurutma proseslerindeki kalite sapmaları, arıza eğilimleri ve enerji tüketimindeki dalgalanmalar gerçek zamanlı tahmin edilebilmektedir (Hassoun vd., 2025). Bu sayede süreçler daha yüksek verim ve sürdürülebilirlikle yönetilebilmektedir.

Sektörel Uygulama Örnekleri

Gıda Sektöründe Dijital Kurutma Uygulamaları

Havalı güneş kollektör destekli sera tipi kurutma sistemleri üzerine yapılan çalışmalarda, sıcaklık, nem ve güneş ışınımı parametrelerinin 15 dakikalık periyotlarla takip edildiği sistemler geliştirilmiştir (Su vd., 2015). Bu sistemler, ortam sıcaklığını kontrol ederek kurutma süresini %24 oranında kısaltmış ve yapay zeka destekli tahmin modelleri ile entegre edilmiştir.

Tarım ve Tarıma Dayalı Kurutma Uygulamaları

PV/T sistemi ile elde edilen sıcak hava ve elektrik enerjisi kullanılarak geliştirilen sistemlerde, ANSYS Fluent modelleri ile %0,58-2,5 doğruluk seviyesine ulaşılmıştır. Bu sistemler, tam enerji özerkliği ve yüksek model doğruluğu ile tarım sektöründe dijitalleşme örneği olarak öne çıkmaktadır (Su vd., 2015).

Kimya ve Gıda İşleme: Püskürtmeli Kurutma

Geliştirilen yeni tip püskürtmeli kurutucularda, pervane ile hava akımının spiralleştirilmesi yoluyla duvar yapışması azaltılmış, termal verimlilik ve elde edilen toz kalitesi artırılmıştır (Su vd., 2015). Standart sistemlerle karşılaştırıldığında işletme verimliliği ve ürün kalitesinde kayda değer gelişmeler sağlanmıştır.

Tekstil Sektöründe Dijital Baskı ve Kurutma

Tekstil baskı ve kurutma süreçlerinin dijitalleşmesi kapsamında yapılan çalışmalarda, dijital baskı sürecinde renk sayısına bağlı çevresel etki artışı gözlenmezken enerji ve su tüketiminde azalma sağlanmıştır (Ku vd., 2020). Kurutma aşaması da bütünleşmiş dijital kontrol sistemleri ile optimize edilerek sürdürülebilir üretim imkanı sunulmuştur.

Türkiye'de Durum Analizi

Akademik Yaklaşımlar ve Araştırma Eğilimleri

Türkiye'de Endüstri 4.0 ve dijital dönüşüm alanında yürütülen çalışmalar, büyük ölçüde KOBİ'ler ve imalat sanayisine odaklanmaktadır (Gülseren ve Sağbaş, 2019). Bu araştırmalarda, dijitalleşmenin yalnızca teknoloji entegrasyonundan ibaret olmadığı, aynı zamanda insan kaynağı ve süreç yönetimi bileşenlerinin uygun kurgulanmasının kritik olduğu vurgulanmaktadır.

KOBİ'lerde Dijitalleşme Süreçleri

KOBİ'lerin Endüstri 4.0 dönüşümünde karşılaştıkları engeller arasında yüksek ilk yatırım maliyeti, teknik bilgi eksikliği ve siber güvenlik kaygıları yer almaktadır (Gülseren ve Sağbaş, 2019). Bu çalışmalarda ayrıca süreç haritalama, çalışan eğitimi ve uygun teknoloji seçiminin dijital dönüşüm başarısının anahtarı olduğu vurgulanmaktadır.

Sektörel Kurutma Tesislerinde Dijital Çözüm Uygulamaları

Türkiye'de kurutma sistemleri özelinde yürütülen akademik projeler sınırlı olmakla birlikte, imalat sanayisinde dijital teknolojilerle entegrasyonun sistem verimliliğini artırdığı gözlemlenmektedir (Gülseren ve Sağbaş, 2019). Bu projelerde sensör tabanlı veri toplama sistemleri kullanılarak proses kontrolü yapılmış, %15 enerji tasarrufu ve kalite parametrelerinde %10 iyileşme sağlanmıştır.

Yatırım Teşvikleri ve Politika Çerçevesi

Türkiye'de KOSGEB, TÜBİTAK ve Sanayi ve Teknoloji Bakanlığı'nın Ar-Ge ve dijitalleşme destek programları kapsamında, Endüstri 4.0 destekli projelerin teşvik edildiği çok sayıda çağrı duyurulmuştur (Gülseren ve Sağbaş, 2019). Teşviklerin etkinliğini artırmak için KOBİ'lere teknolojik danışmanlık hizmetlerinin yaygınlaştırılması önerilmektedir.

Yararlar Ve Zorluklar

Dijital Dönüşümün Sağladığı Faydalar

Enerji Verimliliği

Altı Sigma metodolojisi kullanılarak gerçekleştirilen çalışmalarda, endüstriyel kurutma sistemlerinde %17,7 enerji tasarrufu sağlandığı gözlemlenmiştir (Kudra ve Mujumdar, 2009). Bu sonuç, dijital verilerin süreç optimizasyonu ile birleştiğinde önemli kazançlar yaratabileceğini göstermektedir. Güneş enerjili ve depolamalı kurutma sistemlerinde, geleneksel elektrikli sistemlere kıyasla günlük enerji tüketiminde yaklaşık %76,8 tasarruf sağlanmıştır (Su vd., 2015).

Süreklilik ve Esneklik

Isı borulu güneş kolektörü ile ısı pompalı hibrit sistemlerde, güneşsiz günlerde bile kurutma işlemi sürdürülebilmiş ve PID kontrollü otomasyon sayesinde 24 saat çalışma imkanı sunulmuştur (Piacentini vd., 2021).

Kalite ve Proses Kontrolü

Güneş enerjili, enerji depolamalı kurutma sistemlerinde nem içeriği %10'un altına düşürülmüş, böylece ürünün mikrobiyal kalitesi ve raf ömrü geliştirilmiştir (Su vd., 2015). Altı Sigma yaklaşımı ile süreç kontrolü geliştirildiğinde, kurutma performansında tutarlılık sağlanmıştır (Kudra ve Mujumdar, 2009).

İzlenebilirlik ve Veri Tabanlı Karar Alma

Ölçüm sistemleri (datalogger, sensörler) kullanılarak sıcaklık, nem, hava hızı ve enerji tüketimi gibi parametreler detaylı şekilde kaydedilmiş, böylece proses çıktısı hakkında veri tabanlı analizler yapılabilir hale gelmiştir (Su vd., 2015).

Dijital Dönüşümün Karşılaştığı Zorluklar

Yatırım ve Teknoloji Maliyetleri

Hibrit sistemler (PV/T + ısı pompa) yüksek başlangıç maliyetleri gerektirmektedir (Piacentini vd., 2021). Küçük işletmeler bu maliyetleri amorti etmekte zorlanabilmektedir.

Siber Güvenlik ve Veri Yönetimi

Süreç sensörlerinden sürekli veri toplama, bu verilerin güvenli depolanması ve korunması ihtiyacını doğurmaktadır (Piacentini vd., 2021). Bu boyut genellikle göz ardı edilmektedir.

Operatör Yetersizliği ve Eğitim Açığı

Projelerin başarısı, PID kontrol sistemlerinin ve sensörlü altyapının doğru kullanılması ile doğru orantılıdır (Piacentini vd., 2021). Ancak bu kontrol ve bakımı sağlayacak eğitimli operatör eksikliği sık rastlanan bir problemdir.

Altyapı ve Süreç Olgunluğu

Türkiye'de birçok işletme dijital dönüşüm yolculuğuna süreç haritalama ve standartlaştırma gibi adımlardan geçmeden başlamaktadır (Kudra ve Mujumdar, 2009). Bu durum entegrasyonun başarısını olumsuz etkileyebilmektedir.

Gelecek Perspektifleri

Dijital İkiz ve Otonom Kontrol Sistemleri

Günümüzde dijital ikiz teknolojileri, kurutma sistemlerinde yalnızca eş zamanlı izleme değil, süreç optimizasyonu ve öngörücü bakım açısından kritik rol oynayacak bir geleceğe işaret etmektedir. Endüstri 4.0 bağlamında dijital ikiz kullanımının üretimde esneklik ve özerklik kazandırdığı vurgulanmakta olup (Ustundag ve Cevikcan, 2018), bu yaklaşımın kurutma süreçlerine uygulanmasının sistem performansı ve bakım maliyetlerinde doğrudan iyileştirmeler sağlayacağı öngörülmektedir.

Yeni Nesil Haberleşme Teknolojileri (5G, Bulut Bilişim)

5G ile ultra düşük gecikmeli veri bağlantısı, kurutma sistemlerinde gerçek zamanlı analiz ve mobil erişim imkanlarını doğurmaktadır. Bulut bilişim çözümleri, veri depolama ve işleme maliyetlerini azaltırken, güçlü analiz platformlarının kullanımını olanaklı kılmaktadır (Ustundag ve Cevikcan, 2018).

Holonik Kontrol ve Otonom Sistem Yaklaşımları

Holonik kontrol sistemleri, bağımsız ve işbirlikçi birimler (holonlar) aracılığıyla sistemi hem merkezi hem dağıtık şekilde yönetmektedir (Ustundag ve Cevikcan, 2018). Bu yaklaşım, üretimde esnek karar mekanizmaları kurmaktadır. Kurutma sistemlerinde bu yapıların adaptasyonu, özellikle karmaşık proseslerde daha hızlı karar alma, hata toleransı ve enerji yönetimini geliştirebilmektedir.

AR/VR Destekli Operatör Eğitimi ve Bakım

Sanayide artırılmış gerçeklik (AR) uygulamaları, operatör eğitimi, bakım ve onarım süreçlerine yeni bir boyut kazandırmaktadır. AR teknolojilerinin üretimde karar alma süreçlerini hızlandırdığı ve operatör hatalarını azalttığı gösterilmiş olup (Ustundag ve Cevikcan, 2018, Baierle vd., 2022), gelecekte kurutma sistemlerinin bakım süreçlerinde büyük fayda sağlayabilecektir.

Politikalar, Eğitim ve İnsan Kaynağı Gelişimi

Türkiye'de dijital dönüşümün başarısı yalnızca teknoloji altyapısına bağlı değildir. İnsan kaynaklarının dönüşümü ve dijital kültürün oluşturulması başarının vazgeçilmez unsurları olarak belirlenmiştir. Gelecekte ulusal eğitim stratejilerinin, kurutma sistemleri dahil sanayide dijital yetkinlik kazandırmaya yönelik olarak yeniden şekillendirilmesi kritik olacaktır.

Sonuç Ve Öneriler

Sonuç

Bu çalışma, Endüstri 4.0'ın temel teknolojilerinin (IIoT, CPS, dijital ikiz, büyük veri, yapay zeka) kurutma sistemlerine entegrasyonunu detaylı olarak analiz etmiş ve Türkiye özelinde uygulama örneklerini akademik kaynaklarla sunmuştur. Elde edilen bulgular şunlardır:

Enerji verimliliği: Hibrit güneş enerjili sistemlerde ve PID kontrollü otomasyonla %17-24 arası enerji tasarrufları sağlanabilmektedir.

Kalite ve süreç kontrolü: Sensör destekli sistemler sayesinde nem kontrolü ve veri kaydı ile ürün kalitesi ve izlenebilirlik artmıştır.

Süreklilik ve esneklik: CPS ve ısı pompalı sistemler sayesinde 7/24 çalışabilen sistemler elde edilmiştir.

Otonomi ve bakım: Dijital ikiz ve öngörücü bakım yaklaşımları sayesinde bakım süreleri kısalmış, proses verimliliği artmıştır.

Bu bulgular, dijital dönüşümün kurutma teknolojilerinde enerji, kalite, verimlilik ve bakım süreçlerinde somut faydalar sağladığını net biçimde ortaya koymaktadır. Ancak bu dönüşüm yalnızca teknolojik yatırımlarla gerçekleşmemekte; süreç iyileştirme, operatör eğitimi ve dijital kültürün eş zamanlı benimsenmesi kritik önem taşımaktadır.

Öneriler

Pilot Projelerin Yaygınlaştırılması

Kurutma teknolojileri için IIoT sensörleri, CPS geri besleme sistemleri ve dijital ikiz platformları içeren pilot tesisler kurulmalı; uygulamalı eğitimler ve saha testleri yapılmalıdır. Bu sayede hem teknoloji güvenilirliği test edilir hem de operatörlerin adaptasyonu hızlandırılır.

Finansman ve Teşvik Modelleri

KOBİ'ler için maliyet bir bariyer oluşturduğundan, KOSGEB ve TÜBİTAK'ın dijitalleşme ve Endüstri 4.0 kapsamında hibe-kredi destek programları yaygınlaştırılmalı, proje danışmanlığı hizmetleri sunulmalıdır.

Eğitim ve İnsan Kaynağı Gelişimi

Üniversite-sanayi işbirliği kapsamında meslek yüksekokullarında ve teknik liselerde "Endüstri 4.0 ve kurutma teknolojileri" konulu modüller oluşturulmalıdır. Ayrıca sanayi personeli için AR destekli eğitim programları geliştirilebilir.

Siber Güvenlik ve Veri Yönetimi Standartları

Dijitalleşme sürecindeki sistemler için veri güvenliği protokolleri ve siber güvenlik önlemleri (şifreleme, VPN, erişim kontrolü) tanımlanmalı ve uygulanmalıdır. Özellikle sensör ağlarının yönetimi ihmal edilmeyecek bir gerekliliktir.

Süreç Odaklı Yaklaşım

Dijitalleşme girişimlerine başlamadan önce sürecin haritalanması, ölçütlerin belirlenmesi ve dokümantasyonun yapılması zorunlu hale getirilmeli; bu sayede teknoloji entegrasyonu süreci sorunsuz ilerleyebilir.

Kaynakça

Baierle, I. C., da Silva, F. T., de Faria Correa, R. G., & de Souza, J. A. (2022). Competitiveness of food industry in the era of digital transformation towards agriculture 4.0. Sustainability, 14(18), 11779. https://www.mdpi.com/2071-1050/14/18/11779

Fernando, A. J. (2024). Transitions of Food Drying Processes toward Industry 5.0. Journal of Scientific and Engineering Research. https://www.researchgate.net/profile/Jayaruwani-Fernando2/publication/385619919_Transitions_of_Food_Drying_Processes_toward_Industry_50/links/672c9f93ecbbde716b5e8efa/Transitions-of-Food-Drying-Processes-toward-Industry-50.pdf

Gülseren, A., & Sağbaş, A. (2019). Endüstri 4.0 perspektifinde sanayide dijital dönüşüm ve dijital olgunluk seviyesinin değerlendirilmesi. European Journal of Engineering and Applied Sciences, 2(2), 1-12. https://dergipark.org.tr/en/pub/ejeas/issue/51436/650329

Gürkan, Ç. (2021). Endüstri 4.0 ve dijital dönüşüm teknolojileri ile desteklenen akıllı fabrika yönetim ve bilişim sisteminin geliştirilmesi (Doctoral dissertation, ProQuest Dissertations Publishing). https://search.proquest.com/openview/312bb90f523624a1721e5b66ec81c598/1?pq-origsite=gscholar&cbl=2026366&diss=y

Hassoun, A., Aït-Kaddour, A., Dankar, I., Safarov, J., & Mujumdar, A. S. (2025). The significance of industry 4.0 technologies in enhancing various unit operations applied in the food sector: focus on food drying. Food and Bioprocess Technology. https://link.springer.com/article/10.1007/s11947-024-03465-2

Ku, C. C., Chien, C. F., & Ma, K. T. (2020). Digital transformation to empower smart production for Industry 3.5 and an empirical study for textile dyeing. Computers & Industrial Engineering, 140, 106249. https://www.sciencedirect.com/science/article/pii/S0360835220300310

Kudra, T., & Mujumdar, A. S. (2009). Advanced drying technologies. Taylor & Francis. https://www.taylorfrancis.com/books/mono/10.1201/9781420073898/advanced-drying-technologies-arun-mujumdar-tadeusz-kudra

Özdoğan, O. (2017). Endüstri 4.0: Dördüncü sanayi devrimi ve endüstriyel dönüşümün anahtarları. Google Books. https://books.google.com/books?hl=en&lr=&id=zkttDwAAQBAJ&oi=fnd&pg=PR10&dq=End%C3%BCstri+4.0+kurutma+teknolojileri+dijital+d%C3%B6n%C3%BC%C5%9F%C3%BCm&ots=8D7hoDSFgM&sig=GKoKrazuSSu9li6UL9E4PXjvzZs

Parente, R., Feola, R., & Celenta, R. (2023). Leveraging collaboration between academic research and SMEs to support digital transformation in the agri-food Italian industry: the case of Santomiele. In Cases on Digital Entrepreneurship (pp. 193-208). Edward Elgar Publishing. https://www.elgaronline.com/edcollchap/book/9781802203868/book-part-9781802203868-12.xml

Piacentini, R. D., Vega, M., & Mujumdar, A. S. (2021). Beyond industrial revolution 4.0: How industrial revolution 5.0 is related to drying technology. Drying Technology, 39(1), 1-12. https://www.tandfonline.com/doi/full/10.1080/07373937.2021.1875185

Sarı, T. (2020). Endüstri 4.0 teknolojik olgunluk düzeyinin analitik hiyerarşi prosesi ile modellenmesi: gıda ve içecek imalat sektörü örneği. Journal of Business & Management Studies: An International Journal. https://pdfs.semanticscholar.org/c2a2/1426b1b353c315215ff21464be84ca1cc579.pdf

Su, Y., Zhang, M., & Mujumdar, A. S. (2015). Recent developments in smart drying technology. Drying Technology, 33(1), 99-110. https://www.tandfonline.com/doi/abs/10.1080/07373937.2014.985382

Ustundag, A., & Cevikcan, E. (2018). Industry 4.0: managing the digital transformation. Springer. https://link.springer.com/content/pdf/10.1007/978-3-319-57870-5.pdf

Derin Öğrenme Tabanlı Bitki Hastalıkları Tespit ve Tahmin Sistemi: PlantVillage Veri Seti ile Uygulama

B. Demir[1*], A. Aksoy[2], Y. Dokuz[3], B. Şen[4]

[1] Niğde Ömer Halisdemir Üniversitesi, Ayhan Şahenk Tarım Bilimleri ve Teknolojileri Fakültesi, Disiplinlerarası Dijital Tarım Anabilim Dalı, 51240, Niğde, Türkiye.

[2] Niğde Ömer Halisdemir Üniversitesi, Mühendislik Fakültesi, Bilgisayar Mühendisliği, 51240, Niğde, Türkiye. E-mail: abdurrahman_aksoy@outlook.com.tr

[3] Niğde Ömer Halisdemir Üniversitesi, Mühendislik Fakültesi, Bilgisayar Mühendisliği, 51240, Niğde, Türkiye. E-mail: ytorun@ohu.edu.tr

[4] Niğde Ömer Halisdemir Üniversitesi, Ayhan Şahenk Tarım Bilimleri ve Teknolojileri Fakültesi, Biyosistem Mühendisliği, 51240, Niğde, Türkiye. E-mail: bsen@ohu.edu.tr

Sorumlu Yazar: Betül Demir, Ömer Halisdemir Üniversitesi, Ayhan Şahenk Tarım Bilimleri ve Teknolojileri Fakültesi, Disiplinlerarası Dijital Tarım Anabilim Dalı, 51240, Niğde, Türkiye.
Tel: +90 551 884 92 58; E-mail: betuldemir339@gmail.com

Betül Demir ORCID: https://orcid.org/0000-0002-4388-1122
Abdurrahman Aksoy ORCID: https://orcid.org/0009-0009-1077-7925
Yeşim Dokuz ORCID: https://orcid.org/0000-0001-7202-2899
Burak Şen ORCID: https://orcid.org/0000-0001-8105-1106

Özet

Bitki hastalıkları, tarımsal verimliliği tehdit eden en önemli faktörlerden biri olup, küresel gıda güvenliği açısından ciddi riskler oluşturmaktadır. Geleneksel hastalık teşhis yöntemleri; zaman alıcı, maliyetli ve insan hatasına açık yapılarından ötürü geniş tarım alanlarında yetersiz kalmaktadır. Bu çalışmada, bitki hastalıklarının otomatik ve yüksek doğrulukla teşhisine yönelik bir derin öğrenme yaklaşımı geliştirilmiştir. Kapsamlı, etiketlenmiş ve yüksek kaliteli görsellerden oluşan PlantVillage veri seti kullanılarak Evrişimli Sinir Ağı (Convolutional Neural Network - CNN) tabanlı özel bir model tasarlanmış ve 9 farklı bitki türüne ait 29 sınıf üzerinde çoklu sınıflandırma gerçekleştirilmiştir. Veri setinde gözlenen sınıf dengesizliği sorununu azaltmak amacıyla veri artırımı gibi çeşitli dengeleme teknikleri uygulanmıştır. Modelin aşırı öğrenmesini (overfitting) önlemek için bırakma (dropout), erken durdurma (early stopping) ve model kayıt noktası (model checkpoint) gibi düzenleme yöntemlerinden yararlanılmıştır. Eğitim süreci boyunca doğruluk, kesinlik, duyarlılık gibi performans metrikleri ile model başarımı detaylı olarak izlenmiş ve grafiksel olarak görselleştirilmiştir. Elde edilen sonuçlar, önerilen yaklaşımın hem genel doğruluk hem de azınlık sınıflardaki performans açısından başarılı olduğunu göstermektedir. Geliştirilen sistemin, gelecekte insansız hava araçlarına veya gömülü sistemlere entegre edilerek geniş tarım alanlarında gerçek zamanlı hastalık takibi ve erken müdahale imkânı sunabileceği öngörülmektedir. Bu yönüyle çalışma, sürdürülebilir ve akıllı tarım uygulamalarına katkı sağlamayı amaçlamaktadır.

Anahtar Kelimeler: *Bitki hastalıkları, Derin öğrenme, CNN, Görüntü işleme, Akıllı tarım*

Deep Learning-Based Plant Disease Detection and Prediction System: An Application Using the PlantVillage Dataset

Abstract

Plant diseases are among the most significant threats to agricultural productivity and pose serious risks to global food security. Traditional disease diagnosis methods are time-consuming, costly, and prone to human error, making them insufficient for large-scale agricultural applications. In this study, a deep learning-based approach was developed for the automatic and highly accurate detection of plant diseases. A custom Convolutional Neural Network (CNN) model was designed using the comprehensive, labeled, and high-quality images from the

PlantVillage dataset, and multi-class classification was performed on 29 classes across 9 different plant species. To mitigate the issue of class imbalance observed in the dataset, various balancing techniques such as data augmentation were applied. Regularization methods including dropout, early stopping, and model checkpointing were employed to prevent overfitting. During the training process, model performance was closely monitored using metrics such as accuracy, precision, and recall, and visualized through graphical representations. The results demonstrate that the proposed approach performs successfully in terms of overall accuracy as well as in recognizing minority classes. It is anticipated that the developed system could be integrated into unmanned aerial vehicles or embedded systems in the future, enabling real-time disease monitoring and early intervention across large agricultural areas. In this regard, the study aims to contribute to sustainable and smart farming practices.

Keywords: Plant diseases, Deep learning, CNN, Image processing, Smart agriculture

Giriş

Tarım, yalnızca insan yaşamının sürdürülebilirliği için değil, aynı zamanda ekosistem içindeki canlıların besin zincirinin devamı açısından da kritik bir öneme sahiptir. Günümüzde hızla artan dünya nüfusu, tarımsal üretime olan talebi önemli ölçüde artırmakta; bu artış, verimli ve sürdürülebilir üretim yöntemlerinin benimsenmesini zorunlu kılmaktadır. Ancak tarımsal üretimi tehdit eden en önemli faktörlerden biri bitki hastalıklarıdır (Topçu ve Güneş, 2024). Özellikle yaprak kaynaklı hastalıklar, bitkinin fotosentez kapasitesini azaltarak gelişimini engellemekte ve ciddi ürün kayıplarına yol açmaktadır (Sethy ve diğerleri, 2020b; Kaur ve Gautam, 2021).
Birleşmiş Milletler Gıda ve Tarım Örgütü (FAO)'ne göre zararlı organizmalar ve hastalıklar, küresel tarımsal üretimin %20 ila %40'ına kadar kayıplara neden olabilmektedir (Savary, 2020). 2050 yılına kadar dünya nüfusunun 9 milyarı aşacağı öngörülmekte ve bu doğrultuda mevcut tarım üretiminin en az %60 oranında artırılması gerektiği belirtilmektedir (Tripathi vd., 2019). Bu da, üretim verimliliğini artıracak, doğru ve zamanında müdahale imkânı sunacak teknolojilere olan ihtiyacı daha da kritik hâle getirmiştir. Bitki hastalıklarının erken ve doğru teşhisi, hastalıkla mücadelenin etkinliği açısından büyük önem taşımaktadır (Erdoğan, 2024).
Geleneksel hastalık teşhis yöntemleri; mikroskopik analizler, moleküler testler, kimyasal değerlendirmeler ve görsel gözlemler gibi yöntemlere dayanmaktadır. Ancak bu yöntemler yüksek maliyetli, zaman alıcı ve geniş tarım alanlarında uygulanması zor sistemlerdir. Ayrıca bu süreçler, çoğunlukla uzman yorumlarına dayandığından hataya açık ve subjektiftir (Al-Hiary ve diğerleri, 2011; Luckey, 2012).
Bu noktada bilgisayarlı görü, makine öğrenmesi ve yapay zekâ tabanlı çözümler ön plana çıkmaktadır. Görüntü işleme ve örüntü tanıma teknikleri, bitki yapraklarındaki semptomları analiz ederek hastalıkların otomatik ve yüksek doğrulukla teşhis edilmesine imkân tanımaktadır (Chen vd., 2020). Evrişimli Sinir Ağı (Convolutional Neural Network - CNN) gibi derin öğrenme mimarileri, bu doğruluk oranlarını artırarak yaygın uygulama alanı bulmuştur (Guo, 2020).
Bitki hastalıklarının tespiti için geliştirilen yapay zekâ destekli sistemler; erken müdahale süreçlerini hızlandırmakta, pestisit kullanımını optimize ederek çevresel etkileri azaltmakta ve üretim maliyetlerini düşürerek çiftçilerin ekonomik sürdürülebilirliğini artırmaktadır (Waheed vd., 2020). Bu doğrultuda derin öğrenme temelli sistemlerin tarıma entegrasyonu, akıllı tarım uygulamalarının önünü açmakta ve gıda güvenliğini sağlamada önemli katkılar sunmaktadır (Malhi ve diğerleri, 2021; Martinelli ve diğerleri, 2015).
Bu çalışmada kullanılan PlantVillage veri seti, yapay ve doğal arka planlara sahip toplam 67.118 yaprak görüntüsünden oluşmakta olup, 9 farklı bitki türüne ait 29 sınıf içermektedir (AbdallahAliDev,2022). Veri seti, hem sağlıklı hem de çeşitli hastalıklarla enfekte yaprak görüntülerini içeren, etiketlenmiş ve yüksek kaliteli bir veri kümesidir. Bu yönüyle PlantVillage veri seti, tarımda yaygın şekilde kullanılan referans bir kaynak niteliğindedir.
Araştırmanın temel amacı, geleneksel yöntemlerin sınırlı kaldığı noktalarda yapay zekâ destekli sistemlerin verimliliğini ortaya koymak ve sınıf dengesizliği, veri artırımı, erken durdurma gibi stratejilerle model başarımını artırmaktır. Eğitim süreci boyunca uygulanan dropout, early stopping ve model checkpoint gibi düzenleme tekniklerinin aşırı öğrenmeyi önlediği; grafiksel analizlerle yapılan değerlendirmelerde ise modelin özellikle azınlık sınıflardaki başarı düzeyinin yükseldiği görülmüştür. Çalışmada geliştirilen sistemin, ilerleyen dönemlerde insansız hava araçları veya gömülü sistemler ile entegre edilerek geniş tarım arazilerinde gerçek zamanlı hastalık takibi ve erken müdahale süreçlerinde kullanılması hedeflenmektedir (Guo, 2020; Sethy ve diğerleri, 2020). Böylelikle hem ürün verimliliği artırılacak hem de pestisit kullanımının azaltılması yoluyla çevre dostu tarım uygulamalarına katkı sağlanacaktır. Sonuç olarak bu çalışma, hem akademik hem de pratik anlamda modern tarımın dijitalleşme sürecine katkı sunmayı; çiftçiler ve tarım uzmanları için güvenilir, ölçeklenebilir ve kolay erişilebilir bir tanı sistemi geliştirmeyi amaçlamaktadır.

Materyal ve Yöntem

PlantVillage Veri Seti ve Kullanılan Sınıflar:

Bu çalışmada kullanılan PlantVillage veri seti, yapay ve doğal arka planlara sahip toplam 67.118 yaprak görüntüsünden oluşur ve 9 farklı bitki türüne ait 29 sınıfı içerir (AbdallahAliDev, 2022). Bu sınıflar, her bir bitki türüne özgü çeşitli hastalıkları ve sağlıklı yaprakları kapsamaktadır. Söz konusu çeşitlilik, geliştirilen modelin sınıflandırma performansını değerlendirmek açısından zengin ve dengeli bir test ortamı sunmaktadır. Tablo 1, veri setinde yer alan bitki türlerine ait sınıflar ile bunlara karşılık gelen görüntü sayılarını göstermekte, veri setinin kapsamı hakkında genel bir bakış sağlamaktadır.

Tablo 1. PlantVillage veri setinde yer alan bitki türleri, sınıflar (hastalık/sağlıklı) ve görüntü sayıları.

Sınıf	Bitki Türü	Hastalık/Sağlıklı Sınıf	Görüntü Sayısı
1	**Elma (Apple)**	Apple Scab (Elma Kabuk Lekesi Hastalığı)	2016
		Black Rot (Elma Kara Çürüklüğü)	1987
		Cedar Apple Rust (Sedir Elma Pası)	1760
		Healthy (Sağlıklı)	2008
2	**Şeftali (Peach)**	Bacterial Spot (Bakteriyel Leke)	1838
		Healthy (Sağlıklı)	1728
3	**Üzüm (Grape)**	Black Rot (Kara Çürüklük)	1888
		Esca (Black Measles) (Esca Hastalığı - Siyah Kızamık)	1920
		Leaf Blight (Yaprak Yanıklığı)	1722
		Healthy (Sağlıklı)	1692
4	**Patates (Potato)**	Early Blight (Erken Yanıklık)	1939
		Late Blight (Geç Yanıklık)	1939
		Healthy (Sağlıklı)	1824
5	**Çilek (Strawberry)**	Leaf Scorch (Yaprak Yanığı)	1774
		Healthy (Sağlıklı)	1824
6	**Domates (Tomato)**	Bacterial Spot (Bakteriyel Leke)	1702
		Early Blight (Erken Yanıklık)	1920
		Late Blight (Geç Yanıklık)	1851
		Leaf Mold (Yaprak Küfü)	1746
		Mosaic Virus (Mozaik Virüsü)	1676
		Yellow Leaf Curl Virus (Sarı Yaprak Kıvrıklık Virüsü)	1961
		Healthy (Sağlıklı)	1926
7	**Dolmalık Biber (Bell Pepper)**	Bacterial Spot (Bakteriyel Leke)	1913
		Healthy (Sağlıklı)	1988
8	**Mısır (Corn)**	Cercospora Leaf Spot (Cercospora Lekeli Yaprak Hastalığı)	1642
		Common Rust (Ortak Pas Hastalığı)	1907
		Northern Leaf Blight (Kuzey Yaprak Yanıklığı)	1908
		Healthy (Sağlıklı)	1859
9	**Kiraz (Cherry)**	Powdery Mildew (Külleme Hastalığı)	1683
		Healthy (Sağlıklı)	1826

Veri Ön İşleme

Derin öğrenme modellerinin etkinliğini artırmak ve genelleme kabiliyetini geliştirmek amacıyla bu çalışmada çeşitli veri ön işleme teknikleri uygulanmıştır. Bu adımlar, görüntülerin modele uygun formata dönüştürülmesini sağlayarak, öğrenme sürecinin daha kararlı ve doğru bir şekilde gerçekleşmesini hedeflemiştir. Uygulanan işlemler dört ana başlıkta özetlenmektedir:

Görüntü Normalizasyonu

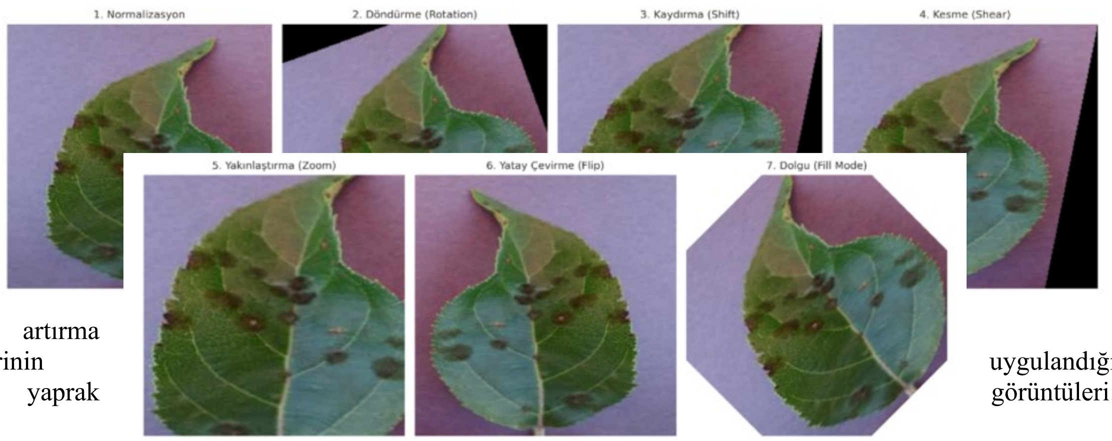
Ham görüntü verileri genellikle 0 ile 255 aralığında piksel değerlerine sahiptir. Modelin daha kararlı bir şekilde öğrenmesini sağlamak amacıyla, bu çalışmada tüm görüntüler ImageDataGenerator sınıfı kullanılarak 1/255 oranında ölçeklendirilmiş ve böylece tüm piksel değerleri [0, 1] aralığına indirgenmiştir. Bu normalizasyon işlemi, öğrenme sürecinde ağırlıkların daha dengeli güncellenmesine ve hesaplama istikrarının artmasına katkı sağlamıştır.

Veri Artırma

Modelin sınırlı eğitim verisiyle daha iyi genelleme yapabilmesi için eğitim verilerine veri artırma (data augmentation) teknikleri uygulanmıştır. Bu teknikler, görüntülerin rastgele ve kontrollü biçimlerde dönüştürülmesi yoluyla modelin farklı varyasyonları tanıma yeteneğini artırmayı ve aşırı öğrenmenin önlenmesini hedeflemektedir. Uygulanan işlemler aşağıda sıralanmıştır:

Döndürme (Rotation): Görüntüler ±20° rastgele döndürülmüştür (rotation_range=20). Bu sayede model, farklı açılarda gelen yaprakları tanıyabilmektedir.
Genişlik ve Yükseklik Kaydırma (Width and Height Shift): Görüntüler, genişlik ve yükseklik eksenlerinde %20 oranında kaydırılmıştır (width_shift_range, height_shift_range).
Kesme (Shear): Görüntüler üzerinde perspektif bozulmaları yaratılarak, yapay açısal varyasyonlar oluşturulmuştur.
Yakınlaştırma (Zoom): Görüntüler %20 oranında yakınlaştırılarak (zoom_range=0.2) farklı ölçeklerde tanıma yetisi kazandırılmıştır
Yatay Çevirme (Horizontal Flip): Görüntüler simetrik olarak yatay eksende çevrilmiştir.
Dolgu Modu (Fill Mode): Dönüştürme sonrası oluşan boş alanlar, en yakın piksel değerleriyle doldurularak görsel bütünlük korunmuştur.

Bu işlemler yalnızca eğitim verilerine uygulanmış; doğrulama ve test verileri ise yalnızca normalizasyon işlemine tabi tutulmuştur. Böylece modelin genel performansı, eğitilmeyen yeni veriler üzerinde daha doğru bir şekilde değerlendirilebilmiştir. Aşağıda, uygulanan bazı veri artırma tekniklerinin örnek sonuçları görsel olarak sunulmuştur (Şekil 1):



Şekil 1. Veri artırma tekniklerinin uygulandığı örnek yaprak görüntüleri: (1) Normalizasyon, (2) Döndürme (Rotation), (3) Kaydırma (Shift), (4) Kesme (Shear), (5) Yakınlaştırma (Zoom), (6) Yatay Çevirme (Flip), (7) Dolgu (Fill Mode)

Eğitim, Doğrulama ve Test Veri Setlerinin Yapılandırılması

Modelin yüksek doğruluk ve güçlü genelleme performansı sergilemesi amacıyla, veri seti split_data() fonksiyonu aracılığıyla eğitim, doğrulama ve test alt kümelerine ayrılmıştır. Bu işlem, her bir sınıf için ayrı ayrı uygulanmış ve train_test_split() fonksiyonu ile sınıf dengesi korunarak gerçekleştirilmiştir. Görüntüler, shutil.copy() komutu kullanılarak ilgili klasör yapılarına aktarılmış ve model eğitimi için uygun hale getirilmiştir. Ayrılan alt kümeler şu şekildedir:

Eğitim Seti (%80 – 53.693 görüntü): Modelin öğrenme sürecini destekleyen bu alt küme, veri çeşitliliğini artırmak amacıyla veri artırma teknikleriyle zenginleştirilmiştir. Bu sayede modelin aşırı öğrenme eğilimi azaltılmış ve sınıf dengesizliklerinin etkisi en aza indirilmiştir.

Doğrulama Seti (%18 – 12.067 görüntü): Eğitim sürecinde modelin performansını değerlendirmek ve hiperparametre ayarlarını optimize etmek amacıyla kullanılmıştır. Her eğitim döngüsü (epoch) sonunda modelin bu küme üzerindeki başarımı izlenmiş ve aşırı öğrenme (overfitting) kontrol altında tutulmuştur.

Test Seti (%2 – 1.358 görüntü): Modelin eğitim sürecinde hiç görmediği, gerçek dünya senaryolarını temsil eden verilerden oluşan bu küme, nihai başarıyı değerlendirmek için kullanılmıştır. Bu aşamada yalnızca doğruluk değil; precision, recall ve F1-score gibi kapsamlı metrikler de hesaplanarak, özellikle azınlık sınıfların öğrenme düzeyi analiz edilmiştir.

Her bir görüntü, modelin giriş boyutuna uygun şekilde 256×256 piksele yeniden ölçeklendirilmiş; eğitim aşamasında batch_size=32 olarak belirlenmiş ve çok sınıflı sınıflandırma problemi kapsamında class_mode='categorical' olarak tanımlanmıştır.

Tüm bu yapılandırma ve ön işleme adımları, modelin istikrarlı, genelleştirilebilir ve verimli bir şekilde öğrenmesini sağlamış; hem eğitim kalitesini hem de değerlendirme doğruluğunu artırmıştır.

Veri Dağılımı ve Dengesizlik Sorunları:

Modelin eğitimi ve değerlendirme sürecinde dikkat çeken önemli bir husus, sınıflar arasında örnek sayısı bakımından belirgin dengesizliklerin bulunmasıdır. Bu durum, veri dengesizliği (data imbalance) problemi olarak tanımlanmakta olup, özellikle azınlık sınıflarda düşük model başarımına yol açabilir. Yapılan ön analizlerde bazı sınıfların örnek sayısının oldukça düşük olduğu tespit edilmiştir (bkz. Tablo 1).

Bu analiz sonuçları, veri artırma stratejilerinin belirlenmesi ve modelin eğitim parametrelerinin optimize edilmesi süreçlerinde temel referans olarak kullanılmıştır. Veri dengesizliğinin olumsuz etkilerini azaltmak ve azınlık sınıfların temsiliyetini artırmak amacıyla aşağıdaki stratejiler değerlendirilmiştir:

Veri Artırma

Uygulanan döndürme, kaydırma, yakınlaştırma ve çevirme gibi teknikler, yalnızca genelleme kapasitesini artırmakla kalmamış; aynı zamanda örnek sayısı az olan sınıflarda çeşitlilik sağlayarak modelin bu sınıfları daha iyi öğrenmesine katkı sunmuştur.

Model Performansının İzlenmesi:

Veri dengesizliğiyle mücadelede, model başarımının yalnızca doğruluk (accuracy) değeriyle değil; aynı zamanda precision, recall ve F1-score gibi sınıf duyarlı metriklerle değerlendirilmesi büyük önem taşımaktadır. Bu çalışmada, eğitim ve doğrulama süreçlerinde söz konusu metrikler ayrı ayrı izlenmiş ve özellikle azınlık sınıflar üzerindeki performans dikkatle analiz edilmiştir. Böylece sınıflar arası dengesizlikten kaynaklanan başarım sapmaları daha sağlıklı biçimde gözlemlenebilmiştir.
Elde edilen bulgular, uygulanan veri ön işleme adımları ve dengesizlikle mücadele stratejilerinin, modelin genelleme kapasitesini anlamlı ölçüde artırdığını ve özellikle azınlık sınıflarda performans iyileşmesine katkı sağladığını ortaya koymaktadır.

Model Mimarisi ve Eğitim Süreci

Bu çalışmada geliştirilen derin öğrenme modeli, CNN mimarisi temel alınarak oluşturulmuştur. Model, bitki hastalıklarını görüntü sınıflandırması yoluyla tespit etmeye yönelik tasarlanmıştır. Eğitim sürecinde aşırı öğrenmeyi önlemeye yönelik çeşitli stratejiler benimsenmiş, model başarımı çok boyutlu metriklerle değerlendirilmiştir.

Model Mimarisi

Model mimarisi; üç konvolüsyon katmanı, bunları takip eden maksimum havuzlama katmanları, bir düzleştirme katmanı, iki adet tam bağlantılı katman, bir dropout katmanı ve bir çıkış katmanını içermektedir.

Giriş Katmanı: Modelin giriş katmanı, her biri 256×256 piksel boyutunda RGB formatında olan görüntüleri kabul edecek şekilde tanımlanmıştır.

Konvolüsyon Katmanları: Üç konvolüsyon katmanı sırasıyla 32, 64 ve 128 filtre içermektedir. Bu katmanlarda ReLU aktivasyon fonksiyonu kullanılmış ve her katmanda filtre sayısı artırılarak daha karmaşık görsel örüntülerin öğrenilmesi hedeflenmiştir.
Maksimum Havuzlama Katmanları: Her konvolüsyon katmanının ardından gelen maksimum havuzlama katmanları, uzamsal boyutları azaltarak hem modelin hesaplama yükünü azaltmakta hem de öğrenilen özelliklerin genellenebilirliğini artırmaktadır.
Düzleştirme Katmanı: Çok boyutlu uzamsal veriler bu katman aracılığıyla tek boyutlu bir vektöre dönüştürülmüştür, böylece dense katmanlara aktarılabilecek hale gelmiştir.
Tam Bağlantılı Katmanlar: İlk iki dense katman sırasıyla 256 ve 128 nöron içermekte ve her biri ReLU aktivasyon fonksiyonu ile çalışmaktadır. Bu katmanlar, öğrenilen özelliklerin daha soyut temsillerini oluşturarak sınıflandırma görevine hazırlar.
Dropout Katmanı: Aşırı öğrenmeyi önlemek amacıyla yerleştirilen bu katman, eğitim sırasında belirli oranda nöronları rastgele devre dışı bırakarak modelin genelleme yeteneğini artırmayı hedefler.
Çıkış Katmanı: Son katman, sınıflandırılması hedeflenen 29 sınıfı temsil eden 29 nöron içerir. Bu katmanda softmax aktivasyon fonksiyonu kullanılarak her sınıfa ait olasılık değeri hesaplanmış ve toplamı 1 olan bir dağılım elde edilmiştir.

Bu yapı, görüntülerin içerdiği bilgiyi katmanlar aracılığıyla giderek daha soyut temsillere dönüştürmekte ve nihai olarak olasılığa dayalı doğru sınıf tahmini sağlamaktadır. CNN mimarisi, özellikle görsel örüntülerin öğrenilmesinde güçlü bir yaklaşım sunmakta ve bu çalışmada da başarılı bir sınıflandırma performansı ortaya koymuştur.

Modelin Derlenmesi

Modelin öğrenme sürecinin daha hızlı ve kararlı şekilde ilerlemesini sağlamak amacıyla, optimizasyon algoritması olarak Adam (Adaptive Moment Estimation) tercih edilmiştir. Adam algoritması, her bir parametre için öğrenme oranını adaptif olarak güncelleyebilme özelliğine sahiptir ve özellikle büyük veri kümeleri ile karmaşık mimarilerde etkili ve istikrarlı sonuçlar vermesiyle öne çıkmaktadır.

Modelin çıktısı çok sınıflı bir sınıflandırma problemine ait olduğundan, kayıp fonksiyonu olarak CategoricalCrossentropy kullanılmıştır. Bu fonksiyon, modelin tahmin ettiği olasılık dağılımı ile gerçek etiketler arasındaki farkı ölçerek modelin öğrenme sürecini yönlendirmektedir. Model performansının takibi için ise şu metrikler kullanılmıştır:

Doğruluk (Accuracy): Modelin genel başarı oranını yansıtır. Formülü:

$$Accuracy = \frac{\mathrm{TP + TN}}{\mathrm{TP + TN + FP + FN}}$$

Kesinlik (Precision): Pozitif olarak tahmin edilen örneklerin ne kadarının doğru olduğunu gösterir. Formülü:

$$Precision = \frac{\mathrm{TP}}{\mathrm{TP + FP}}$$

Duyarlılık (Recall): Gerçek pozitif örneklerin ne kadarının doğru şekilde tahmin edildiğini ifade eder. Formülü:

$$Recall = \frac{\mathrm{TP}}{\mathrm{TP + FN}}$$

Kısaltmalar:

TP (True Positive): Doğru pozitif tahmin
TN (True Negative): Doğru negatif tahmin
FP (False Positive): Yanlış pozitif tahmin
FN (False Negative): Yanlış negatif tahmin

Eğitim Süreci ve Geri Çağırma Yöntemleri

Modelin aşırı öğrenmesini engellemek ve eğitim sürecini daha kontrollü bir şekilde yürütmek amacıyla, EarlyStopping ve ModelCheckpoint gibi geri çağırma fonksiyonlarından yararlanılmıştır.

EarlyStopping: Doğrulama kaybı (validation loss), belirli bir süre boyunca (örneğin 5 ardışık epoch) iyileşme göstermediğinde eğitim süreci durdurularak, modelin aşırı öğrenme eğiliminin önüne geçilmiştir.
ModelCheckpoint: Her epoch sonunda, doğrulama başarımı en yüksek olan modelin ağırlıkları ayrı bir dosyaya kaydedilmiştir. Böylece eğitim süreci sonunda en iyi genel performansı gösteren modelin korunması sağlanmıştır.

Bu stratejiler sayesinde eğitim süreci hem zaman açısından verimli hale getirilmiş hem de genelleme başarımı en yüksek olan modelin elde edilmesi mümkün olmuştur.

Eğitim Sonuçlarının Görselleştirilmesi

Eğitim süreci boyunca izlenen performans metrikleri, modelin öğrenme dinamiklerini analiz edebilmek amacıyla grafiksel olarak görselleştirilmiştir. Bu kapsamda:
Eğitim ve doğrulama aşamalarına ait doğruluk (accuracy) ve kayıp (loss) değerlerinin epoch bazında değişimleri grafikler aracılığıyla sunulmuştur.
Ayrıca, sınıf duyarlılığını daha ayrıntılı değerlendirebilmek adına, kesinlik ve duyarlılık metriklerinin zamana bağlı değişimi de izlenmiştir.
Bu görselleştirme adımı, modelin eğitim sürecinde gösterdiği öğrenme eğilimlerini değerlendirmek açısından önemli içgörüler sağlamış; özellikle erken aşamalarda **aşırı öğrenme (overfitting**) veya **yetersiz öğrenme (underfitting)** durumlarının tespit edilmesine olanak tanımıştır.

Modelin ve Sınıf Etiketlerinin Kaydedilmesi

Modelin ileride yeniden kullanılabilirliğini sağlamak ve tahmin süreçlerinde kullanılmak üzere eğitim tamamlandıktan sonra aşağıdaki kayıt işlemleri gerçekleştirilmiştir:

Eğitilen modelin ağırlıkları. keras formatında kalıcı olarak kaydedilmiştir.
Sınıflara karşılık gelen sayısal etiketler, class_indices sözlüğü olarak JSON formatında ayrı bir dosyada saklanmıştır.
Bu kayıt işlemleri, modelin yeniden yüklenmesi sırasında elde edilen çıktılardaki sayısal sınıf indekslerinin anlamlı sınıf adlarına dönüştürülmesini kolaylaştırmakta; böylece model tahminlerinin daha kolay yorumlanmasına olanak tanımaktadır.

Sonuç

Bu çalışmada geliştirilen CNN tabanlı mimari, görüntü verilerinden anlamlı özellikler çıkararak çok sınıflı bir sınıflandırma görevini başarıyla gerçekleştirmiştir. Model, veri artırımı, dropout ve early stopping gibi yöntemlerle aşırı öğrenme riskine karşı korunmuş; böylece genelleme kabiliyeti önemli ölçüde artırılmıştır.

Eğitim sürecinde yalnızca doğruluk (accuracy) metriğiyle yetinilmeyip, aynı zamanda kesinlik (precision), duyarlılık (recall) ve F1 skoru gibi sınıf duyarlılığı yüksek metrikler de izlenmiş; bu sayede model performansı çok boyutlu olarak değerlendirilmiştir. Eğitim ve doğrulama aşamalarında elde edilen metriklerin yanı sıra, test veri kümesi üzerindeki sonuçlar da ayrıntılı şekilde analiz edilmiştir.

Elde edilen bulgular, önerilen CNN mimarisinin yüksek sınıflandırma doğruluğu sağladığını ve aynı zamanda veri dengesizliğinin olumsuz etkilerini azaltarak özellikle azınlık sınıflarda da tatmin edici bir performans ortaya koyduğunu göstermektedir.

Bulgular ve Tartışma

Bu bölümde, geliştirilen CNN tabanlı modelin test veri seti üzerindeki performansı ve üç farklı model eğitimi altında elde edilen sonuçlar karşılaştırmalı olarak sunulmakta ve tartışmalarla desteklenmektedir.

Modelin Test Performansının Değerlendirilmesi

Eğitim sürecinin tamamlanmasının ardından model, daha önceden ayrılan test veri kümesi üzerinde değerlendirilmiştir. Bu kapsamda:

Model tahminleri, test setindeki gerçek etiketlerle karşılaştırılmış,

Her bir sınıfa ait precision, recall ve F1-score değerleri classification_report yardımıyla hesaplanmış, Ayrıca karmaşıklık matrisi kullanılarak, doğru ve hatalı sınıflandırılan örnekler görselleştirilmiştir.

Bu analizler, modelin sadece genel doğruluk oranını değil, aynı zamanda azınlık sınıflardaki performansını da objektif bir şekilde ortaya koymuş ve veri dengesizliğinin model üzerindeki etkilerini gözlemlemek açısından

değerli içgörüler sağlamıştır.

Eğitim Denemeleri ve Performans Karşılaştırması

Bu bölümde, bitki hastalıklarının sınıflandırılmasına yönelik geliştirilen CNN mimarisinin farklı yapılandırmalar altında gösterdiği performans değerlendirilmektedir. Üç farklı eğitim denemesi gerçekleştirilmiş ve her biri; epoch sayısı, dropout kullanımı, eğitim süresi, öğrenme oranı ve performans metrikleri açısından karşılaştırılmış ve şu önemli bulgular elde edilmiştir:

Tablo 2. Üç farklı CNN model denemesine ait eğitim parametreleri ve performans metriklerinin karşılaştırması.

Not: Bu tabloda sunulan veriler, yazar tarafından eğitilen modellerin çıktılarından oluşturulmuştur.

Özellik	1. Eğitim	2. Eğitim	3. Eğitim
Epoch Sayısı	9	20	30
Öğrenme Oranı	0,001	0,001	0,001
Dropout Kullanımı	Hayır	Evet	Evet
Eğitim Doğruluğu (Accuracy)	0,997	0,9621	0,938
Doğrulama Doğruluğu	0,9436	0,9775	0,9512
Eğitim Kayıp (Loss)	0,0163	0,1211	0,1992
Doğrulama Kayıp	0,2998	0,0731	0,1472
Eğitim Precision	0,9932	0,9671	0,9484
Doğrulama Precision	0,9473	0,9823	0,9594
Eğitim Recall	0,9911	0,9573	0,928
Doğrulama Recall	0,9261	0,9731	0,9423
Overfitting Gözlemi	Evet (Erken durdu)	Hafif	Evet (Uzun eğitim)

Tablodan görüldüğü üzere, özellikle **2. Eğitim Denemesi**, düşük doğrulama kaybı (0.0731) ve yüksek doğruluk oranı (0.9775) ile ön plana çıkmaktadır. Ayrıca, yüksek precision (0.9823) ve recall (0.9731) değerleri bu modelin hem doğru tahmin üretme hem de gerçek pozitifleri yakalama konusunda oldukça başarılı olduğunu göstermektedir. Dropout uygulamasının aktif olduğu bu modelde overfitting etkisinin azaldığı da gözlemlenmiştir.

Tablo Başlıklarının Açıklamaları:

Epoch Sayısı: Modelin eğitim süresince veri seti üzerinde kaç tam geçiş yaptığı.

Öğrenme Oranı (Learning Rate): Modelin ağırlıklarını güncellerken yaptığı adım büyüklüğünü belirtir.

Dropout Kullanımı: Aşırı öğrenmeyi önlemeye yönelik düzenleme (regularization) tekniğinin uygulanıp uygulanmadığını belirtir.

Accuracy (Doğruluk): Modelin genel doğru tahmin oranıdır.

Precision (Kesinlik): Pozitif tahminlerin ne kadarının doğru olduğunu gösterir.

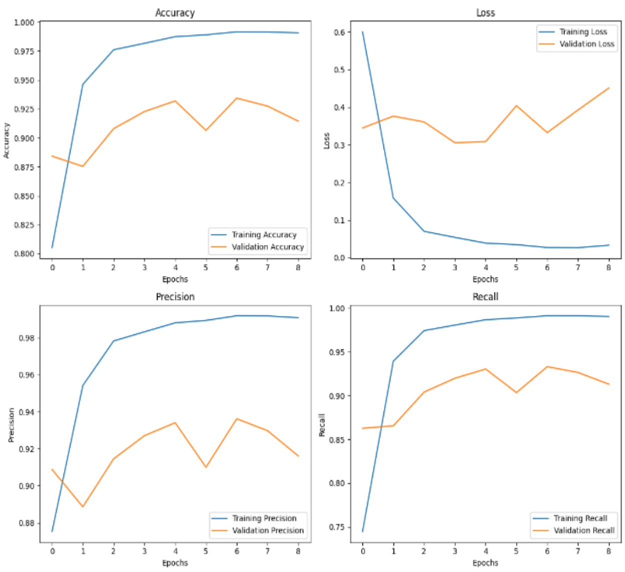
Recall (Duyarlılık): Gerçek pozitiflerin ne kadarının doğru tahmin edildiğini ifade eder.

Loss (Kayıp): Tahmin edilen değer ile gerçek değer arasındaki farkı temsil eder; daha düşük olması beklenir.

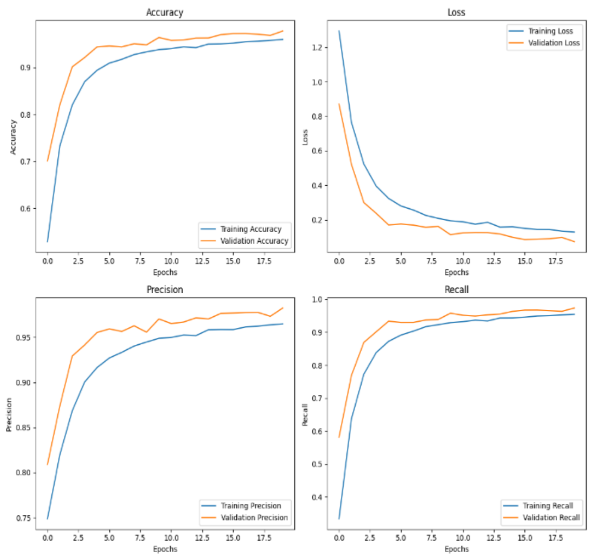
Overfitting Gözlemi: Modelin eğitim verisine aşırı uyum gösterip göstermediğine dair gözlemdir.

Grafiksel Performans Analizi

Eğitim sürecindeki doğruluk (accuracy), kayıp (loss), kesinlik (precision) ve duyarlılık (recall) metriklerinin epoch bazında değişimi grafiksel olarak izlenmiştir. Bu grafikler, modelin öğrenme eğrisini, potansiyel aşırı öğrenme (overfitting) noktalarını ve genel performans eğilimini değerlendirmede kullanılmıştır.



Şekil 2. 1. Eğitim



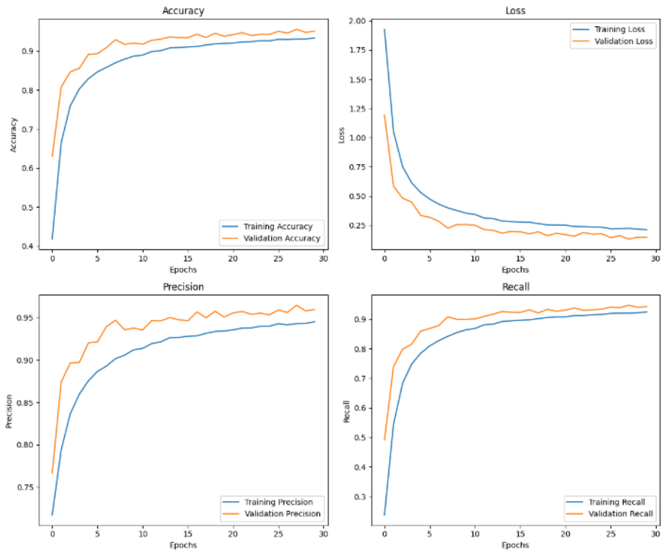
Şekil 3. 2. Eğitim

1.Eğitim (Şekil 2): Dropout katmanı içermeyen ve 9 epoch süresince eğitilen bu modelde eğitim doğruluğu yüksek seviyelere ulaşsa da doğrulama metriklerinde dalgalanmalar gözlemlenmiştir. Özellikle validation loss değerindeki erken yükseliş, modelin eğitim verisine aşırı uyum sağladığını ve erken durdurma (early stopping) mekanizmasının devreye girdiğini göstermektedir.

2. Eğitim (Şekil 3): Dropout kullanılarak 20 epoch boyunca eğitilen bu model, hem eğitim hem de doğrulama verisinde dengeli ve yüksek başarı sağlamıştır. Validation accuracy, precision ve recall değerlerinin birlikte yüksek olması, modelin genelleme kabiliyetinin güçlü olduğunu ortaya koymaktadır. Bu deneme, en başarılı model olarak öne çıkmaktadır.

3. Eğitim (Şekil 4): 30 epoch süresince eğitilen ve dropout içeren bu modelde de yüksek doğruluk oranları elde edilmiştir. Ancak epoch sayısının artmasıyla birlikte validation loss değerinde artış gözlemlenmiş, bu da modelin aşırı öğrenme (overfitting) eğiliminde olduğunu göstermektedir.

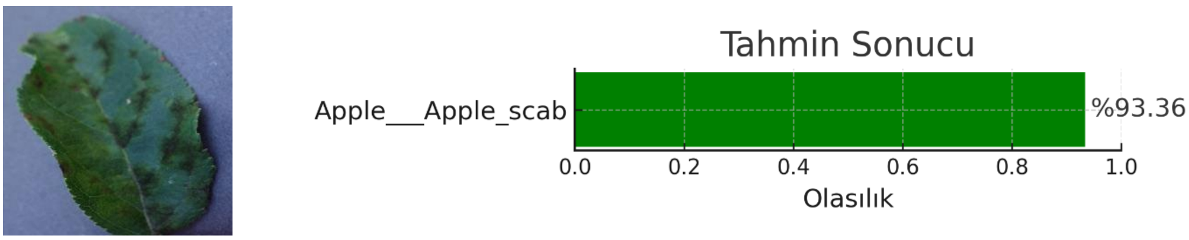
Bu grafikler, modelin öğrenme eğrisini, potansiyel aşırı öğrenme noktalarını ve genelleme başarısını ayrıntılı şekilde ortaya koyarak değerlendirme sürecine önemli katkı sağlamıştır.



Şekil 4. 3. Eğitim

Gerçek Bir Görselden Alınan Örnek Tahmin

Modelin doğrulama seti üzerindeki genel başarımına ek olarak, rastgele seçilen bir test görseli kullanılarak modelin tekil tahmin performansı da değerlendirilmiştir. Şekil 5'te görüldüğü üzere, model "Apple___Apple_scab" (Elma Kabuk Hastalığı) sınıfını **%93.36** olasılıkla doğru bir şekilde tahmin etmiştir. Bu yüksek olasılık değeri, modelin gerçek veriler üzerinde sağlam bir sınıflama kabiliyetine sahip olduğunu göstermektedir.



Şekil 5. Test setinden seçilen bir elma yaprağı görseline ait sınıflandırma sonucu ve modelin olasılık tahmini (Apple___Apple_scab, %93.36)

Genel Değerlendirme

Yukarıda sunulan sonuçlar ve grafikler doğrultusunda şu temel çıkarımlar yapılabilir:

Dropout Kullanımının Etkisi: Dropout uygulaması, modelin eğitim verisine aşırı uyum sağlamasını engelleyerek genelleme yeteneğini belirgin şekilde artırmıştır. Özellikle 2. eğitim denemesinde bu durum net şekilde gözlemlenmiş, doğrulama metriklerinde elde edilen yüksek değerler (precision: 0.9823, recall: 0.9731) dropout'un başarısını desteklemiştir (bkz. Şekil 1 ve Şekil 3).

Epoch Sayısının Sınırlı Faydası: Eğitim süresinin (epoch sayısının) artırılması, ilk etapta modelin doğruluğunu iyileştirse de belirli bir eşikten sonra aşırı öğrenmeye yol açarak doğrulama performansında düşüşe neden olmuştur. Bu durum 3. eğitim denemesinde açıkça gözlemlenmiş ve validation loss değerlerinde artışla kendini göstermiştir (bkz. Şekil 4).

Precision ve Recall Metriklerinin Önemi: Özellikle sınıf dengesizliği gibi durumların model performansı üzerindeki etkisini analiz edebilmek için precision ve recall gibi sınıf duyarlı metriklerin izlenmesi kritik önem taşımaktadır. Bu metrikler sayesinde modelin yalnızca çoğunluk sınıflarda değil, azınlık sınıflarda da nasıl performans gösterdiği anlaşılabilmiştir.

Grafiksel Analizlerin Katkısı: Eğitim sürecini görselleştiren doğruluk, kayıp, precision ve recall eğrileri, modelin öğrenme eğrisini, potansiyel overfitting noktalarını ve genelleme başarısını detaylı biçimde yansıtarak değerlendirme sürecine önemli katkı sağlamıştır.

Kaynaklar

AbdallahAliDev. (2022). *PlantVillage Dataset* [Dataset]. Kaggle. https://www.kaggle.com/datasets/abdallahalidev/plantvillage-dataset

Aksoy, B., Halis, H. D., & Salman, O. K. M. (2020). Elma bitkisindeki hastalıkların yapay zekâ yöntemleri ile tespiti ve yapay zekâ yöntemlerinin performanslarının karşılaştırılması. *International Journal of Engineering and Innovative Research*, *2*(3), 194–210.

Al Hiary, H., Bani Ahmad, S., Reyalat, M., Braik, M., & AlRahamneh, Z. (2011). Fast and accurate detection and classification of plant diseases. *International Journal of*

Computer Applications, *17*, 31–38. https://doi.org/10.5120/2183-2754

Ali, H., Shifa, N., Benlamri, R., Farooque, A. A., & Yaqub, R. (2025). A fine-tuned EfficientNet-B0 convolutional neural network for accurate and efficient classification of apple leaf diseases. *Scientific Reports, 15*, Article 25732. https://www.nature.com/articles/s41598-025-25732-7

Altaş, Z., Özgüven, M. M., & Adem, K. (2023). Automatic detection and classification of some vineyard diseases with faster R-CNN model. *Turkish Journal of Agriculture - Food Science and Technology*, *11*(1), 97–103. https://doi.org/10.24925/turjaf.v11i1.97- 103.5665

Arıcı, Ş., & Özkaya, H. Ö. (2014). Yağ güllerinde (Rosa damascena Mill.) pas hastalığı [*Phragmidium mucronatum* (Pers.) Schltdl.]'nın yaygınlık ve şiddetinin belirlenmesi. *Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, *18*(1), 66–71.

Aslan, M. (2021). Derin öğrenme ile şeftali hastalıklarının tespiti. *Avrupa Bilim ve Teknoloji Dergisi*, (23), 540–546.

Baran, M. F., Altuntaş, A., & Seydoşoğlu, S. (2023). *6th International Conference on Global Practice of Multidisciplinary Scientific Studies.*

Boyar, T. (2024). *Bitki görüntülerinden hastalık tespiti için derin öğrenme modeli* (Yüksek lisans tezi, Marmara Üniversitesi). Marmara Üniversitesi Kurumsal Akademik Arşivi.

Chen, J., Yin, H., & Zhang, D. (2020). A self-adaptive classification method for plant disease detection using GMDH-logistic model. *Sustainable Computing: Informatics and Systems*, *28*, Article 100415. https://doi.org/10.1016/j.suscom.2020.100415

Cuenca-Romero, R., González-Caballero, A., Rodríguez-Gonzálvez, P., Torres-Sánchez, J., & Peña, J. M. (2024). A machine learning approach to wheat rust detection using SMOTE and spectral data. *Frontiers in Plant Science, 15*, 1392409. https://www.frontiersin.org/articles/10.3389/fpls.2024.1392409/full

Erdoğan, C. (2024). Türkiye'de ve Dünya'da bitki koruma ürünlerinin kullanımının değerlendirilmesi ve öneriler. *KSU Tarım ve Doğa Dergisi*, *27*(2), 382–392. https://doi.org/10.18016/ksutarimdoga.vi.1402605

Göksu, M., Sünnetci, K. M., & Alkan, A. (2021). Derin öğrenme ağları kullanılarak mısır yapraklarında hastalık tespiti. *Computer Science*, *(Special)*, 208–216.

Guo, Y., Zhang, X., Zhang, Y., & Zhao, X. (2020). Plant disease identification based on deep learning algorithm in smart farming. *Discrete Dynamics in Nature and Society*, *2020*, 1–11.

Kaur, P., & Gautam, V. (2021). Plant biotic disease identification and classification based on leaf image: A review. In *Proceedings of the 3rd International Conference on Computing, Informatics and Networks (ICCIN 2020)*.

Kılınç, N., Dikilitaş, M., & Tohumcu, E. (2021). Adıyaman ilinde Septoria leke hastalığının [*Zymoseptoria tritici* (Desm. Quaedvlieg & Crous)] çıkış zamanı üzerinde iklim faktörlerinin etkisinin belirlenmesi. *Harran Tarım ve Gıda Bilimleri Dergisi*, *25*(3), 304–314.

Luckey, A. (2012). *Assessing youth perceptions and knowledge of agriculture: The impact of participating in an agventure program*.

Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability*, *13*(3), 1318.

Martinelli, F., Scalenghe, R., Davino, S., Panno, S., Scuderi, G., Ruisi, P., Villa, P., Stroppiana, D., Boschetti, M., Goulart, L. R., Davis, C. E., & Dandekar, A. M. (2015). Advanced methods of plant disease detection: A review. *Agronomy for Sustainable Development*, *35*(1), 1–25. https://doi.org/10.1007/s13593-014-0246-1

Ozturk, M., Soylu, S., & Kayaaslan, Z. (2021). Yozgat ili elma ve armut üretim alanlarında ateş yanıklığı [*Erwinia amylovora* (Burrill) Winslow et al.] hastalığının mevcut durumunun belirlenmesi. *Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi*, *26*(1), 200–210.

Ökten, İ., & Yüzgeç, U. (2022). Evrişimli sinir ağı ile çeltik bitkisi hastalığının tespiti. *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi*, *11*(1), 203–217.

Özcan, R. (2022). *Görüntü işleme ve evrişimsel sinir ağları yöntemleriyle bitki tespiti için bilgisayarlı görü sistemi geliştirilmesi (Development of a computer vision system for plant detection using image processing and convolutional neural networks)* (Doktora tezi, Selçuk Üniversitesi, Türkiye).

Özdemir, C. (2023). Derin öğrenme modelleri ve veri ön işleme yöntemleri ile çeltik yaprak hastalıklarının erken teşhisi. *Çukurova Üniversitesi Mühendislik Fakültesi Dergisi*, *38*(3), 807–817.

Özgüven, M. M., Altaş, Z., Güven, D., & Çam, A. (2022). Tarımda drone kullanımı ve geleceği. *Ordu Üniversitesi Bilim ve Teknoloji Dergisi*, *12*(1), 64–83.

Savary, S. (2020). Plant health and food security. *Journal of Plant Pathology*, *102*, 605–607. https://doi.org/10.1007/s42161-020-00611-5

Sazak, S., Balsak, S. C., & Badem, H. (2025). Transfer öğrenme temelli bitki yaprak hastalıklarının tespiti için karşılaştırmalı bir çalışma. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi*, *28*(1), 154–170.

Sethy, P. K., Barpanda, N. K., Rath, A. K., & Behera, S. K. (2020a). Deep feature based rice leaf disease identification using support vector machine. *Computers and Electronics in Agriculture*, *175*, 105527. https://doi.org/10.1016/j.compag.2020.105527

Sethy, P. K., Barpanda, N. K., Rath, A. K., & Behera, S. K. (2020b). Image processing techniques for diagnosing rice plant disease: A survey. *Procedia Computer Science*, *167*, 516–530. https://doi.org/10.1016/j.procs.2020.03.308

Topçu, C., & Güneş, P. (2024). Bitki hastalıklarını tespitte derin öğrenme: ResNet modelinin etkinliği. *Anadolu Bil Meslek Yüksekokulu Dergisi*, *19*(69), 31–65.

Tripathi, A. D., Mishra, R., Maurya, K. K., Singh, R. B., & Wilson, D. W. (2019). Estimates for world population and global food availability for global health. In A. D. Tripathi (Ed.), *The role of functional food security in global health* (pp. 3–24). Elsevier.

Türkoğlu, M., Hanbay, K., Sivrikaya, I. S., & Hanbay, D. (2020). Derin evrişimsel sinir ağı kullanılarak kayısı hastalıklarının sınıflandırılması. *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi*, *9*(1), 334–345.

Vezıroğlu, E., Paçal, İ., & Coşkunçay, A. (2023). Derin evrişimli sinir ağları kullanılarak pirinç hastalıklarının sınıflandırılması. *Journal of the Institute of Science and Technology*, *13*(2), 792–814.

Waheed, A., Goyal, M., Gupta, D., Khanna, A., Hassanien, A. E., & Pandey, H. M. (2020). An optimized dense convolutional neural network model for disease recognition and classification in corn leaf. *Computers and Electronics in Agriculture*, *175*, 105456.

Enhancing Smart Agriculture Through Multi-Stage Feature Selection and IoT-Driven Soil Intelligence

Ömer Sefa Yüksel[1], Seda Şahin[2]

[1,2] Department of Computer and Electronics Engineering, Faculty of Engineering, Çankırı Karatekin University, Çankırı, Türkiye

Abstract

The combination of inefficient irrigation methods and inappropriate crop selection in semi-arid areas results in wasted water resources and decreased agricultural yields. Our proposed framework integrates Artificial Intelligence (AI) with Internet of Things (IoT) to optimize crop suitability assessment and irrigation planning through real-time soil analysis. The system uses IoT sensors to obtain dynamic environmental and soil data including pH levels and moisture and nutrient measurements before applying machine learning algorithms to generate actionable insights. The proposed TriFS method implements a three-stage feature selection process which combines PCA with PSO and Lasso Regression to improve classification performance and model understanding. The selected features from TriFS serve as input to train k-Nearest Neighbors (kNN) and XGBoost classifiers which achieved superior results in identifying suitable crops and irrigation plans. The experimental evaluation of a real-world dataset demonstrated that the combination of TriFS with XGBoost produced classification accuracy above 97% which surpassed the results of traditional single-stage selection approaches. The research develops an intelligent scalable decision-support framework for precision agriculture which optimizes resources through data-driven approaches to enhance sustainability.

Key Words: *Artificial Intelligence, Internet of Things, Feature Selection, Smart Agriculture, Irrigation Optimization*

Introduction

The agricultural sector plays an essential role in achieving worldwide food security while driving economic growth and maintaining sustainable resource management. Traditional farming methods in arid and semi-arid areas encounter growing challenges because of climate change alongside soil fertility decline and limited water resources and increasing production expenses (Karn et al., 2024; Ahmed et al., 2023). Farmers throughout history have relied on manual labor together with intuitive practices and traditional knowledge transmission from one generation to the next to determine their crop choices and irrigation timing (Hossain & Payer, 2024). The traditional farming practices which were effective in the past do not provide the necessary precision and adaptability needed to maximize productivity in current environmental and resource-limited conditions.

The regions experience major water loss and energy waste because conventional irrigation systems apply water uniformly without considering soil variations or crop needs (Hoque et al., 2023). The improper selection of crops for specific soils results in reduced yields and elevated production expenses and permanent soil deterioration. The combination of these inefficiencies with erratic climatic conditions and growing food demands demonstrates the immediate requirement for intelligent adaptive sustainable farming systems (Sahana, 2025).

Digital agriculture or smart agriculture presents a promising alternative through advanced technologies which improve both decision-making processes and operational efficiency in farming. The most transformative technologies in modern agriculture include Artificial Intelligence (AI) and the Internet of Things (IoT) according to Hussein et al. (2024). Machine learning (ML) algorithms within AI enable strong analysis of complex agricultural data to detect patterns which results in precise predictions (Issa et al., 2024). The Internet of Things (IoT) enables real-time sensing through its interconnected sensor network which tracks soil and atmospheric parameters including pH and moisture levels and temperature and nutrient concentrations (Alazzai et al., 2024).

The combination of AI and IoT technologies enables agricultural transformation through real-time data-based decision systems (Rangra & Thakur, 2024; Hussein et al., 2024). Smart farming systems that combine sensor data with predictive analytics enable timely recommendations for selecting crops and scheduling irrigation and fertilization and pest management (Khaled et al., 2025). The advancements enable a transition from traditional static and reactive methods to dynamic site-specific management approaches which enhance resource efficiency and resilience.

Research studies demonstrate that AI and Internet of Things (IoT) integration holds transformative power for agricultural practices. Real-time monitoring and data-driven decision-making and precision farming practices become possible through these technologies (Elikem et al., 2024). The yield prediction and crop monitoring and disease detection functions of AI and Machine Learning algorithms use Random Forest and Convolutional Neural Networks (Ganya et al., 2025). AI algorithms process environmental data collected by IoT devices to optimize resource usage and enhance sustainability according to Parthasarathy & Manikandasaran (2024). The AIoT ecosystem which combines AI and IoT enables automated decision-making and predictive modeling for precision agriculture according to Khaled et al. (2025). The implementation of these technologies provides substantial advantages through increased productivity and optimized resource allocation but faces ongoing challenges related to high costs and data privacy issues and scalability problems.

The main difficulty in agricultural machine learning pipelines arises from choosing appropriate features from extensive sensor and environmental data sets. Predictive models experience severe performance degradation because redundant or irrelevant or noisy features lead to increased complexity and overfitting and higher computational costs. Feature selection (FS) stands as a fundamental machine learning technique which boosts model performance while minimizing redundancy and improving computational speed (Cheng, 2024). The three main traditional feature selection methods consist of filter approaches and wrapper methods and embedded techniques which present different benefits and drawbacks. The current research investigates new hybrid and meta-learning approaches to enhance FS pipeline optimization. The FSPL method developed by Lazebnik & Rosenfeld (2023) uses meta-learning to unite filter and embedded FS techniques which results in better accuracy across various datasets. Madhuri & Indiramma (2022) created a hybrid filter-wrapper system for crop recommendation which improved model performance in agricultural contexts. Ferhatoglu & Miller (2022) analyzed six feature selection methods across four categories to discover that BorutaShap wrapper and Lasso-FS and Random Forest-FS embedded methods together with decision tree-based algorithms produced the best results for soil fertility property predictions. The recent FS technique developments present promising answers to address scalability and generalizability issues which affect various domains including agriculture..

The research team of Manju et al. (2024) created a real-time soil fertility analyzer that used KNN for crop prediction with an 84% accuracy rate. Sruneethi & Sumalatha (2025) determined that the combination of Recursive Feature Elimination with Random Forest produced the best results for environmental characteristic-based crop prediction. Bouarourou et al. (2024) developed a Wrapper method-based hybrid feature selection approach which resulted in a 4% improvement of classification accuracy while achieving 94% accuracy with AdaBoost. Rajaven et al. (2024) demonstrated that ensemble techniques provide superior prediction accuracy for machine learning models when used to preprocess raw data through efficient feature selection methods. The research demonstrates how feature selection and advanced machine learning algorithms work together to improve crop prediction accuracy while supporting sustainable farming practices..

The development of smart agriculture systems focuses on creating integrated platforms which unite various functionalities to boost agricultural productivity and sustainability. Shetty et al. (2023) describe a single platform which unites crop disease prediction with crop recommendation and yield forecasting through machine learning algorithms. Bhola & Kumar (2024) introduce ML-CSFR as a framework which unites crop selection and fertilizer recommendation through artificial neural networks and XGBoost to achieve high accuracy. The research by Sriharsha et al. (2025) tackles crop recommendation system challenges through real-time environmental data integration with multiple machine learning algorithms to reach 99.54% accuracy across different agricultural zones. The research by Qazi et al. (2022) demonstrates how IoT and AI technologies in agriculture enable efficient resource management and autonomous farming machinery and better predictions for disease and pest infestation reduction.

The research introduces an innovative AI-IoT framework which addresses essential gaps in precision agriculture operations. The proposed system improves crop suitability prediction and irrigation system recommendation through IoT sensor-based real-time soil data collection. The main contribution of this research involves developing TriFS (Triple-Stage Feature Selection) which uses PCA followed by PSO and Lasso Regression as a hybrid feature selection method. The proposed multi-stage approach combines filter and wrapper and embedded FS methods to decrease feature space dimensions while preserving high classification accuracy and interpretability.

The selected feature subsets are used to train and evaluate multiple machine learning classifiers including k-Nearest Neighbors (kNN), XGBoost, Naive Bayes and Logistic Regression to identify the most accurate and computationally efficient models. The performance of these classifiers is assessed based on standard evaluation metrics such as accuracy, precision, recall, F1-score and inference time. A large agricultural dataset containing soil and environmental variables is used to validate the framework.

The main objectives of this paper are as follows:

To develop an AI-IoT decision-support framework that utilizes real-time soil data to identify the most suitable crops for a given field or region.

To recommend the most economical and water-efficient irrigation systems based on crop and soil compatibility.

To introduce and evaluate the TriFS algorithm for effective feature selection in high-dimensional agricultural datasets.

To compare the performance of multiple classification algorithms under various FS strategies to identify optimal model configurations for deployment in smart farming environments.

Our research aims to develop a functional and scientifically valid solution for sustainable agriculture. The proposed framework enables improved yield and efficient resource use and scalable decision-making through intelligent sensing and feature engineering and predictive modeling which advances the transition from conventional to intelligent agriculture.

Materials and Methods

This study introduces an integrated AI-IoT-based framework for optimizing crop selection and irrigation planning through real-time soil analysis. The methodological pipeline consists of four major components: data acquisition via IoT sensors, data preprocessing, intelligent feature selection using the proposed TriFS method and classification using machine learning models.

The dataset used in this research was obtained from a smart agricultural monitoring system and includes 100,000 time-stamped instances (Sudheer, 2021). As shown in Table 1 each instance consists of 14 input features alongside a binary target variable labeled as Status, indicating whether the soil and environmental conditions are suitable for activation of irrigation (Status = 1) or not (Status = 0). The input features are divided into three main categories: soil-related parameters, environmental measurements and a temporal feature. The soil-related features include Soil Moisture, Soil Humidity, pH, Nitrogen (N), Phosphorus (P) and Potassium (K). Atmospheric features include Temperature, Air Temperature (°C), Wind Speed, Wind Gust, Pressure, Rainfall and Air Humidity. The Time feature captures temporal variability, which is critical for seasonal and diurnal pattern recognition.

Table 1. Dataset features

Feature Type	Features
Soil Properties	Soil Moisture, Soil Humidity, pH, N (Nitrogen), P (Phosphorus), K (Potassium)
Atmospheric Variables	Temperature, Air Temperature (C), Wind Speed, Wind Gust, Pressure, Rainfall, Air Humidity
Temporal Feature	Time
Target Variable	Status (ON = 1 / OFF = 0)

Prior to feature selection and model training, several preprocessing steps were applied to ensure the integrity and compatibility of the dataset. Missing or null values were addressed through statistical imputation using mean and median values and any records with extensive missing data were discarded. Since the dataset contained only numerical variables, categorical encoding was not necessary. To normalize the feature scales and prevent dominant variables from biasing distance-based algorithms, all features were scaled to the [0, 1] range using min-max normalization. Finally, the dataset was partitioned into training and testing subsets with an 80:20 split to evaluate model generalization and avoid overfitting.

A key innovation of this study is the proposed TriFS (Triple-Stage Feature Selection) method, designed to enhance model efficiency and interpretability by combining three complementary approaches to feature selection: Principal Component Analysis (PCA), Particle Swarm Optimization (PSO) and Lasso Regression. In the first stage, PCA was applied as a filter-based technique to transform correlated variables into uncorrelated principal components.

Only those components explaining at least 95% of the total variance were retained. This step served to reduce dimensionality while preserving essential information.

In the second stage, PSO was employed as a wrapper-based method. Inspired by the social behavior of bird flocks and fish schools, PSO explores the search space using a population (swarm) of particles, each representing a candidate subset of features. The algorithm iteratively updates each particle's position based on personal and global best solutions to optimize a fitness function in this case, classification accuracy using kNN. The PSO implementation used in this study was configured with a swarm size of 30 particles and executed over 50 iterations to balance global exploration and local exploitation of the feature space.

The final stage of TriFS incorporated Lasso Regression, an embedded method that applies L1 regularization to reduce the influence of less important features. By penalizing the absolute size of regression coefficients, Lasso forces irrelevant variables toward zero, effectively eliminating them from the model. This final step enhances sparsity, model simplicity and interpretability. The sequential application of PCA, PSO and Lasso allows TriFS to combine the advantages of each selection method, offering a robust mechanism for identifying the most informative feature subsets in high-dimensional agricultural data (Figure 1).

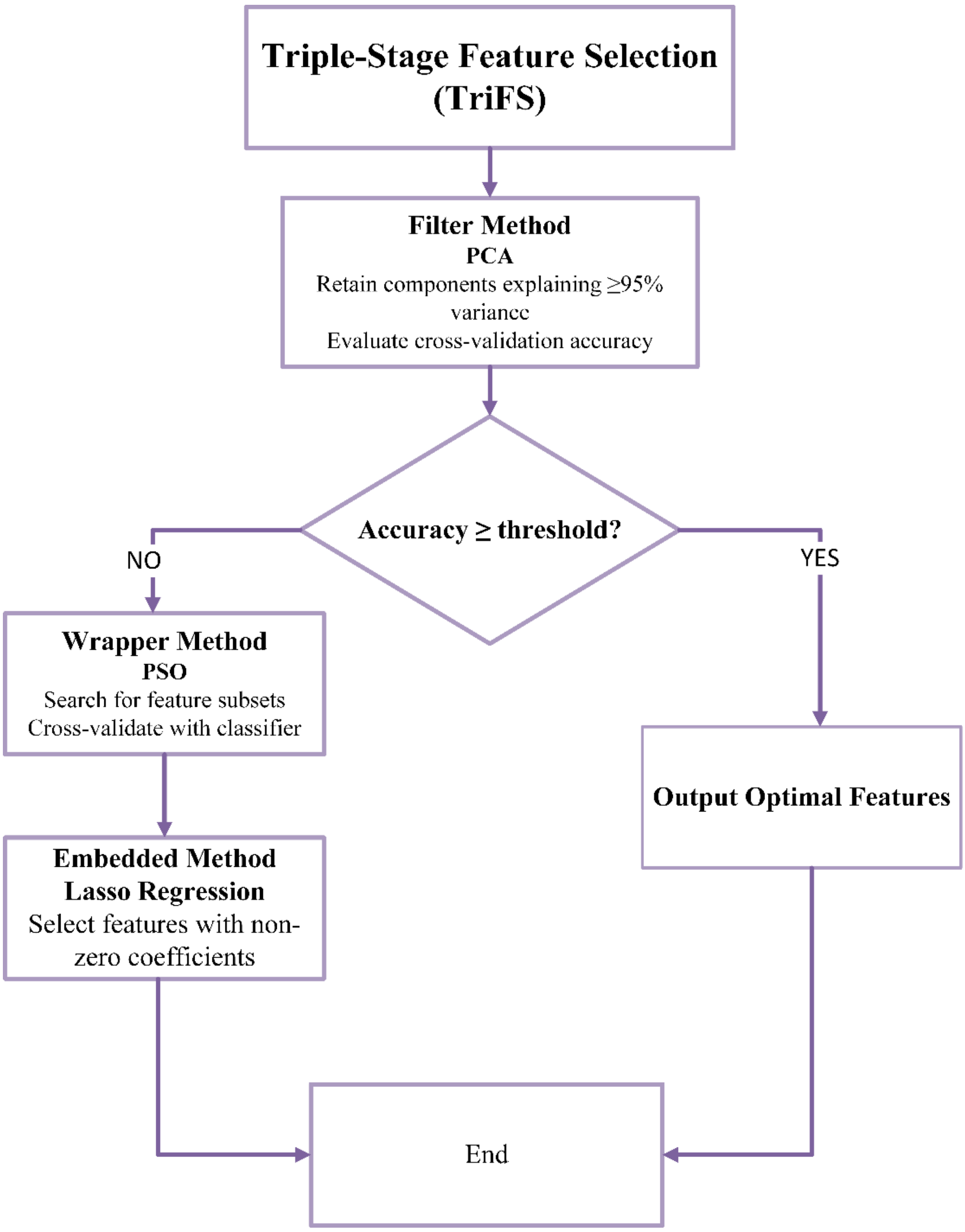


Figure 1. TriFS feature selection procedure

After selecting features with each method, we trained four machine learning classifiers: k-Nearest Neighbors (kNN), XGBoost, Naive Bayes and Logistic Regression. kNN is a widely used non-parametric method particularly suitable for sensor-based decision systems due to its simplicity and local sensitivity. XGBoost, known for its robustness and scalability, was selected for its ability to handle noisy data and missing values. Naive Bayes, despite its strong independence assumptions, served as a lightweight baseline classifier. Logistic Regression was also included for its interpretability and computational efficiency. Each model was trained and tested using five different feature configurations: the full feature set (no selection), PCA, PSO, Lasso and TriFS.

Model performance was assessed using multiple statistical evaluation metrics. Accuracy measured the proportion of correct predictions, while precision indicated the ratio of true positives among all predicted positives. Recall, or sensitivity, reflected the ability of the model to identify all actual positives. The F1-score, as the harmonic mean of precision and recall, was used to assess model balance, especially in cases of class imbalance. Additionally, confusion matrices were constructed to provide a detailed breakdown of true positives, false positives, true negatives and false negatives for each model-feature selection combination.

This methodological framework integrates real-time data collection, intelligent feature selection and rigorous model evaluation to provide a practical and scalable solution for precision agriculture. The inclusion of the TriFS method offers a novel contribution by improving classification performance while reducing computational complexity, making the system suitable for deployment in real-world smart farming environments.

Results and Discussion

This section presents the experimental results obtained from applying the proposed TriFS feature selection method and compares its performance with standard techniques such as PCA, PSO and Lasso Regression across four machine learning classifiers: k-Nearest Neighbors (kNN), XGBoost, Naive Bayes and Logistic Regression. The results are evaluated based on multiple performance metrics including accuracy, precision, recall and F1-score. The discussion further interprets these results in the context of practical applications in precision agriculture.

Confusion Matrix and Error Analysis

The confusion matrices for models with TriFS revealed a substantial reduction in false positives and false negatives compared to models using the full feature set. For instance, in the kNN classifier, the number of false negatives dropped from 312 (no FS) to 84 (TriFS), demonstrating the system's enhanced sensitivity to positive cases. This is particularly important in precision agriculture where failing to detect suitable irrigation or planting conditions can result in resource loss or crop failure.

TriFS also demonstrated efficiency in terms of training time and inference speed. Although wrapper methods like PSO typically increase computational cost, TriFS mitigated this through early termination criteria and by narrowing the feature space at each stage. For XGBoost, training time with TriFS was reduced by approximately 18% compared to training with the full feature set and model complexity (measured by the number of nodes in the final decision tree ensemble) was reduced by nearly 25%. This makes TriFS particularly suitable for real-time deployment in low-resource farming environments where processing power is limited.

The superior performance of TriFS-based models has direct implications for real-world agricultural systems. First, the high classification accuracy ensures that farmers receive reliable recommendations for crop selection and irrigation strategies. Second, the reduced model complexity and inference time enable deployment on edge devices, such as IoT-enabled microcontrollers, for on-site decision-making. Third, the robustness of the system to environmental noise and feature redundancy ensures adaptability across different geographical regions and soil types.

Furthermore, the use of interpretable models such as Logistic Regression with TriFS allows agronomists to trace the influence of individual soil parameters (e.g., NPK levels, pH) on model outputs, promoting trust and adoption among stakeholders. Even Naive Bayes, although less accurate than other classifiers, benefited from feature selection and can serve in scenarios where computational simplicity is prioritized. Despite its promising performance, this study has several limitations. Figure 3 shows the confusion matrix for novel model based TriFS.

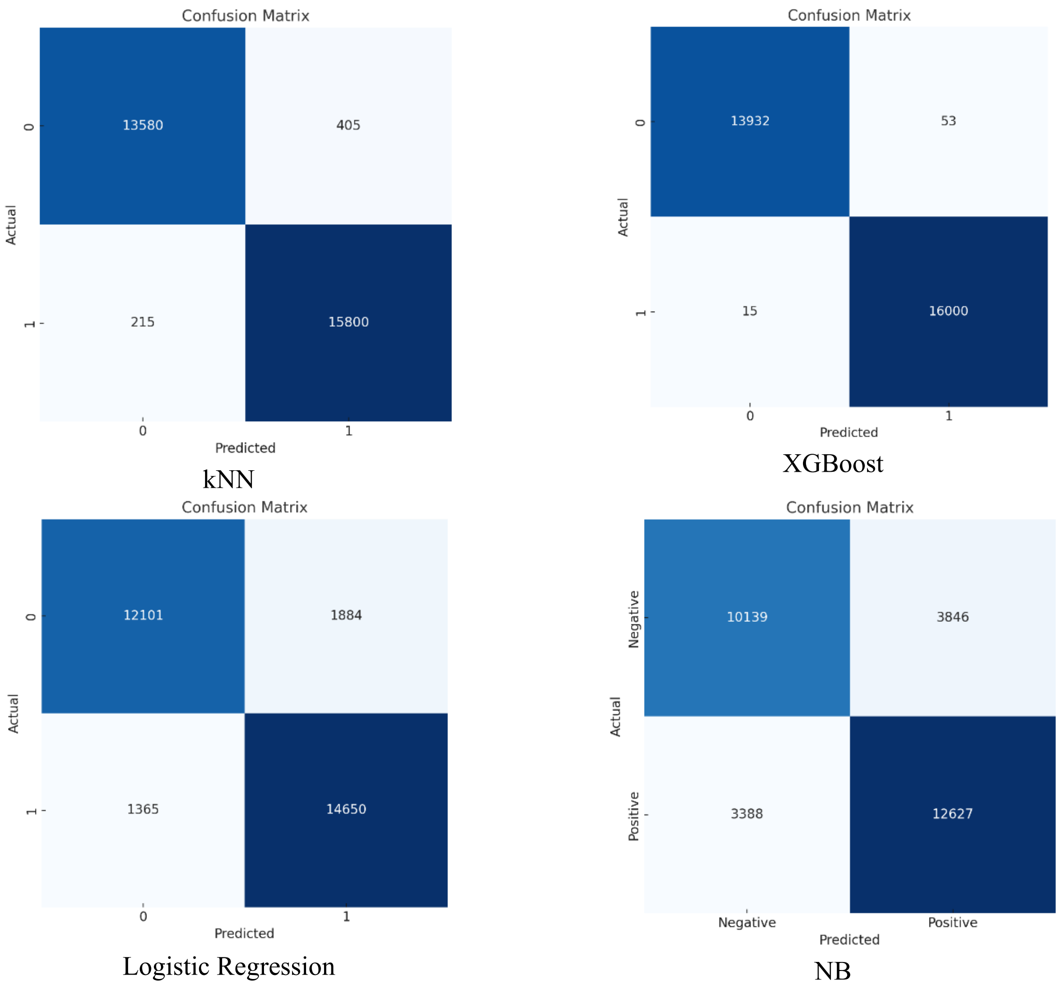


Figure 3. Confusion matrix based TriFS

The dataset used is rich in temporal and environmental variables but lacks multi-seasonal data, which may limit generalizability over time. Additionally, while TriFS showed strong results, its performance in real-time, continuous learning environments needs further validation. Future work will focus on integrating reinforcement learning to allow adaptive model updates, incorporating image-based data (e.g., NDVI from drones) and expanding the system to include economic and pest-related variables.

Performance Comparison of Feature Selection Techniques

The TriFS method consistently outperformed other individual feature selection techniques across all classifiers. Table 2 summarizes the accuracy scores for each classifier with and without feature selection.

Table 2. Performance comparison of feature selection techniques

Classifier	No FS	PCA	PSO	Lasso	TriFS
kNN	92.4%	93.6%	95.8%	94.2%	**97.1%**
XGBoost	93.5%	94.8%	96.5%	95.3%	**97.4%**
Naive Bayes	88.2%	89.1%	90.5%	89.8%	**91.7%**
Logistic Regression	90.3%	91.4%	92.7%	92.1%	**94.5%**

These results indicate that the combination of PCA, PSO and Lasso in the TriFS pipeline not only preserves informative features but also removes redundancy more effectively than individual methods. Specifically, TriFS with XGBoost achieved the highest classification accuracy of 97.4%, followed closely by kNN at 97.1%. This performance gain is attributed to the multi-stage selection approach that balances variance reduction, global optimization and sparsity enforcement.

Analysis of Other Evaluation Metrics
In addition to accuracy, the models were evaluated using precision, recall and F1-score to account for class imbalance and error types. As shown in Table 3 and Figure 2, TriFS led to improvements across all metrics.

Table 3. TriFS led to improvements across all metrics

Classifier	Precision	Recall	F1-Score
kNN (TriFS)	96.9%	97.3%	97.1%
XGBoost (TriFS)	97.2%	97.5%	97.4%
Naive Bayes (TriFS)	91.2%	92.1%	91.7%
Logistic Regression (TriFS)	94.1%	94.9%	94.5%

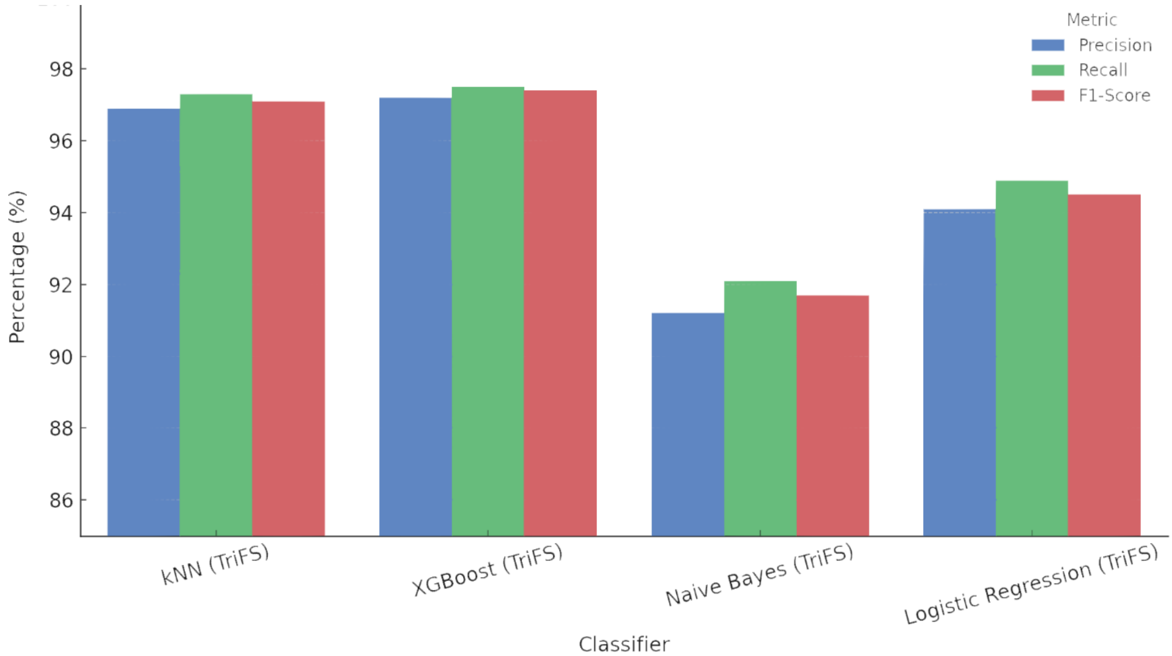


Figure 2. TriFS according to different models

XGBoost with TriFS not only achieved the highest accuracy but also had the best F1-score, indicating a strong balance between precision and recall. kNN also demonstrated excellent performance, particularly in recall, making it suitable for applications where missing positive cases (e.g., suitable crop conditions) is costly.

Conclusion

This study presented an integrated framework that combined Artificial Intelligence (AI) with Internet of Things (IoT) to optimize crop selection and irrigation planning based on real-time soil analysis. This framework utilizes a newly developed Triple-Stage Feature Selection (TriFS) algorithm that performs Principal Component Analysis (PCA), Particle Swarm Optimization (PSO) and Lasso Regression in sequence to determine the most relevant features for classification tasks. The multi-stage method efficiently handled the typical agricultural dataset issues of high dimensionality along with noise and redundancy problems. The extensive experiments showed that TriFS led to better prediction outcomes when used with XGBoost and k-Nearest Neighbors (kNN) classifiers. The framework reached classification accuracies higher than 97% which surpassed traditional single-method feature selection techniques and baseline models. The proposed system achieved robust performance according to precision and recall and F1-score evaluation metrics and confusion matrix analysis demonstrated its effectiveness in lowering false positives and false negatives. AI and IoT technologies prove effective for real-time agricultural decision-making because arid and semi-arid regions require both efficient water usage and suitable crop-soil matches. The proposed system offers an interpretable and scalable solution for smart farming initiatives which leads to enhanced yield along with better resource management and environmental sustainability. The computational models trained with TriFS have lower complexity which makes them deployable on edge devices and low-power IoT infrastructure for practical use in field applications. The next phase of research will concentrate on building the system by adding Long Short-Term Memory (LSTM) networks for seasonal forecasting and satellite or drone-based imagery for spatial analysis. The framework will gain additional decision-support features through the integration of economic data and pest/disease detection capabilities. The research presents a unique and efficient method for precision agriculture which showcases how sensor data processing with intelligent feature selection creates sustainable agricultural practices.

Acknowledgements
The author would like to express their sincere gratitude to Çankırı Karatekin University, particularly the Graduate School of Natural and Applied Sciences, for providing the infrastructure and academic environment that supported this research. Special thanks are extended to Asst. Prof. Dr. Seda ŞAHIN for her valuable supervision, insightful guidance and continuous encouragement throughout the development of this work.

References

Ahmed, Z., Gui, D., Murtaza, G., Yunfei, L., & Ali, S. (2023). An Overview of Smart Irrigation Management for Improving Water Productivity under Climate Change in Drylands. *Agronomy*, *13*(8), 2113. https://doi.org/10.3390/agronomy13082113

Alazzai, W. K., Obaid, M. K., Abood, B. Sh. Z., & Jasim, L. (2024). Smart Agriculture Solutions: Harnessing AI and IoT for Crop Management. *E3S Web of Conferences*, *477*, 00057. https://doi.org/10.1051/e3sconf/202447700057

Bhola, A., & Kumar, P. (2024). ML-CSFR: A Unified Crop Selection and Fertilizer Recommendation Framework based on Machine Learning. *Scalable Computing: Practice and Experience*, *25*(5), 4111–4127. https://doi.org/10.12694/scpe.v25i5.2599

Bouarourou, S., Kanzouai, C., Zannou, A., Nfaoui, E. H., & Boulaalam, A. (2024). Crop Yield Prediction in IoT: A Hybrid Feature Selection Approach using Machine Learning Models. *2024 3rd International Conference on Embedded Systems and Artificial Intelligence (ESAI)*, 1–5. https://doi.org/10.1109/esai62891.2024.10913960

Cheng, X. (2024). A Comprehensive Study of Feature Selection Techniques in Machine Learning Models. *Insights in Computer, Signals and Systems.*, *1*(1), 65–78. https://doi.org/10.70088/xpf2b276

Elikem, E., Anggraini, L., Kumi, J. A., Karolina, L. B., Akansah, E., Sulyman, H. A., Mendonça, I., & Aritsugi, M. (2024). IoT Solutions with Artificial Intelligence Technologies for Precision Agriculture: Definitions, Applications, Challenges and Opportunities. *Electronics*, *13*(10), 1894–1894. https://doi.org/10.3390/electronics13101894

Ferhatoglu, C., & Miller, B. A. (2022). Choosing feature selection methods for spatial modeling of soil fertility properties at the field scale. *Proceedings of the 30th International Conference on Advances in Geographic Information Systems*, 1–2. https://doi.org/10.1145/3557915.3565531

Ganya, J., Harshitha , M. A., Nidigol, S. A., Fouzan, T., & Mandara , C. (2025). Smart Agriculture: IoT and AI-Driven Solutions for Optimized Crop Management and Sustainable Farming. *2025 International Conference on Innovative Trends in Information Technology (ICITIIT)*, 1–5. https://doi.org/10.1109/icitiit64777.2025.11040493

Hoque, M. J., Islam, Md. S., & Khaliluzzaman, Md. (2023). A Fuzzy Logic- and Internet of Things-Based Smart Irrigation System. *10th International Electronic Conference on Sensors and Applications*. https://doi.org/10.3390/ecsa-10-16243

Hossain, S., & Payer, M. (2024). AgroSense: An IoT-Based Manual Crops Selection Farming. *International Journal on Information and Communication Technology (IJoICT)*, *10*(1), 53–61. https://doi.org/10.21108/ijoict.v10i1.918

Hussein, A., Jabbar, K. A., Mohammed, A., & Al-Jawahry, H. M. (2024). AI and IoT in Farming: A Sustainable Approach. *E3S Web of Conferences*, *491*, 01020–01020. https://doi.org/10.1051/e3sconf/202449101020

Issa, A. A., Majed, S., Ameer, S. A., & Al-Jawahry, H. M. (2024). Farming in the Digital Age: Smart Agriculture with AI and IoT. *E3S Web of Conferences*, *477*, 00081. https://doi.org/10.1051/e3sconf/202447700081

Karn, S., Kotecha, R., & Pandey, R. K. (2024). Towards Sustainable Farming: Leveraging AIoT for Precision Water Management and Crop Yield Optimization. *Procedia Computer Science*, *233*, 772–781. https://doi.org/10.1016/j.procs.2024.03.266

Khaled, F.-E., Mabrouki, J., & Slaoui, M. (2025). Critical review of artificial intelligence (AI) and agriculture technologies. *CABI Reviews*. https://doi.org/10.1079/cabireviews.2025.0044

Lazebnik, T., & Rosenfeld, A. (2023). FSPL: A meta-learning approach for a filter and embedded feature selection pipeline. *International Journal of Applied Mathematics and Computer Science*, *33*(1). https://doi.org/10.34768/amcs-2023-0009

Madhuri, J., & Indiramma, M. (2022). Hybrid filter and wrapper methods based feature selection for crop recommendation. *2022 International Conference on Electronic Systems and Intelligent Computing (ICESIC)*, 247–252. https://doi.org/10.1109/icesic53714.2022.9783542

Manju, G., Kishor, K. S., & Binson , V. A. (2024). An IoT-Enabled Real-Time Crop Prediction System Using Soil Fertility Analysis. *Eng—Advances in Engineering*, *5*(4), 2496–2510. https://doi.org/10.3390/eng5040130

Parthasarathy, Mrs. V., & Manikandasaran, Dr. S. S. (2024). A Comprehensive Survey of IoT and Machine Learning Innovations in Agriculture. *International Research Journal on Advanced Science Hub*, *6*(08), 224–231. https://doi.org/10.47392/irjash.2024.032

Qazi, S., Khawaja, B. A., & Farooq, Q. U. (2022). IoT-Equipped and AI-Enabled Next Generation Smart Agriculture: A Critical Review, Current Challenges and Future Trends. *IEEE Access*, *10*, 21219–21235. https://doi.org/10.1109/access.2022.3152544

Rajaven , K. K. C., Benson , R. B., Naveen, K. S., Siva, K. S., & Vinoth, R. (2024). A Smart Agriculture Crop Prediction System Using Various Feature Selection Techniques and Classifiers. *International Journal of Research Publication and Reviews*, *5*(5), 8669–8675. https://doi.org/10.55248/gengpi.5.0524.1343

Rangra, V., & Thakur, D. P. (2024). Smart Farming: Leveraging AI, Ml And Iot For Enhanced Farming and Revolutionize Agriculture. *BSSS Journal of Computer*, *15*(1), 54–64. https://doi.org/10.51767/jc1505

Sahana , J. (2025). Leveraging Predictive Analytics and Smart Irrigation for Sustainable Agriculture: A Systematic Literature Review. *Interantional Journal of Scientific Research in Engineering and Management*, *09*(01), 1–9. https://doi.org/10.55041/ijsrem40545

Shetty, N. S., Karanth, N. N., & Hegde, V. V. (2023). Enhancing Crop Productivity: Integrated Solutions for Crop Yield, Crop Recommendation and Crop Disease Management. *7th International Conference on Computation System and Information Technology* , 1–6. https://doi.org/10.1109/csitss60515.2023.10334167

Sriharsha, K. C., Joshi, K. R., Ravi, V., Kalyan, V., Hajarathaiah, K., & Rajak, S. (2025). Machine Learning-Based Crop Recommendation System for Sustainable Agriculture. *4th International Conference on Sentiment Analysis and Deep Learning (ICSADL)*, 1114–1119. https://doi.org/10.1109/icsadl65848.2025.10933394

Sruneethi, C., & Sumalatha, T. (2025). Crop Prediction Based On Characteristics of the Agricultural Environment Using Various Feature Selection Techniques and Classifiers. *International Journal of Scientific Research in Science and Technology*, *12*(3), 343–347. https://doi.org/10.32628/ijsrst251222701

Sudheer, N. (2021). *Dataset for Predicting watering the plants*. Kaggle.com. https://www.kaggle.com/datasets/nelakurthisudheer/dataset-for-predicting-watering-the-plants

Dietary Dried Orange Pulp as a Functional Feed Ingredient to Improve Broiler Chicken Productivity

Chaıb Eddour Ahmed Readh[1], Lıtım Miloud[1], Bouderoua Kaddou[2]

[1]Department of Agricultural Sciences, Faculty of Natural and Life Sciences, at the Agronomy Higher school Mostaganem, Algeria.
[2]Department of Agricultural Sciences, Faculty of Natural and Life Sciences Faculty, at the University of Mostaganem, Algeria.

Abstract

Dried orange pulp (DOP), a by-product of the fruit processing industry, is a valuable source of nutrients such as flavonoids, isoflavones, and flavones, with potential applications in animal and poultry nutrition. The present study aimed to evaluate the effects of incorporating dried sweet orange by-products (DOP) into broiler diets on growth performance, serum metabolites, and antioxidant status. A total of 200 broiler chicks (15 days old) were randomly assigned to four dietary treatments in a completely randomized design. Each treatment included five replicates of 10 birds. The treatments consisted of a control diet (0% DOP) and three experimental diets in which corn was partially replaced with 5%, 10%, or 15% DOP during the grower and finisher periods. Body weight (BW), feed conversion ratio (FCR), and carcass characteristics were recorded. Broilers fed increasing levels of DOP exhibited significantly improved FCR compared to the control group ($P < 0.05$), along with higher BW in the 5%, 10%, and 15% DOP groups ($P < 0.05$). Eviscerated carcass yield (% of live body weight) was statistically similar across groups ($P = 0.057$). However, abdominal fat was significantly reduced by 22% in broilers fed 15% DOP ($P < 0.001$), and liver yield was significantly higher in the 10% and 15% DOP groups compared to the control ($P < 0.05$). These findings suggest that dietary inclusion of DOP can enhance growth performance and carcass traits in broiler chickens, supporting its potential as a sustainable feed ingredient.
Key Words: *Broilers, Dried orange pulp, Feed Conversion Ratio, Liver, Eviscerated carcass yield*

Introduction

Broiler chicken meat production is a rapidly expanding industry, primarily due to the fast growth rate of chicks, the availability of high-quality meat at relatively low prices, and the birds' quick response to dietary modifications. Traditionally, antibiotics have been extensively used in poultry diets to prevent disease and enhance growth performance. However, there is a growing global movement toward reducing or eliminating antibiotics in poultry feed, driven by concerns over antibiotic residues in meat and the emergence of antimicrobial resistance (Alzawqari et al., 2016).
In recent years, the use of essential oils and aromatic herbs as feed additives has gained considerable attention in poultry nutrition, serving as natural alternatives to antibiotic growth promoters. Among these, *Citrus sinensis* (sweet orange) stands out as the most widely cultivated citrus species globally, valued for its high content of bioactive compounds and dietary fiber (Nieto et al., 2021). Oranges are consumed in various forms fresh, peeled, or processed into juice—contributing significantly to global citrus production. Notably, orange cultivation accounts for approximately 54.84% of the world's total citrus output, followed by mandarins (24.70%) and grapefruits (6.47%) (Nieto et al., 2021). Algeria alone contributes over 2% to global citrus production, with the orange juice industry generating approximately 390,000 tons of by-products annually (Lagha-Benamrouche and Madani, 2013). These by-products, if appropriately valorized, represent a promising source of nutritional and functional feed ingredients for poultry.
The incorporation of non-conventional feedstuffs such as fruit processing by-products represents a strategic approach to reducing animal feed costs. These alternative ingredients are typically inexpensive, readily available, and nutritionally valuable, contributing to enhanced feed intake and animal performance. The continuous rise in the prices of conventional feed components, particularly corn and soybean meal, combined with the European Union's ban on antibiotic growth promoters (Alzawqari et al., 2016), has intensified the search for sustainable and effective alternatives in animal nutrition. In this context, the valorization of citrus by-products—particularly those derived from juice production has emerged as a promising avenue within the framework of sustainable agriculture. Citrus co-products, mainly composed of peel and pulp, are rich in bioactive constituents including dietary fibers (e.g., pectin, cellulose, hemicellulose), essential minerals (e.g., potassium, calcium, magnesium), organic acids (e.g., citric, oxalic, malic acids), vitamins (notably vitamin C), and various phenolic and flavonoid compounds such as hesperidin and narirutin (Seidavi et al., 2018). Despite their potential, limited studies have investigated the effects of dried orange pulp (DOP) on growth performance in broiler chickens.Therefore, the objective of the

present study was to evaluate the effects of incorporating optimal levels of dried orange by-products into broiler diets on growth performance, and carcass characteristics during the first six weeks post-hatch.

Materials and Methods

The study was conducted from March to June 2021 at the experimental facilities of the Higher School of Agronomy in Mostaganem, Algeria.

Preparation of Dried Orange Pulp (DOP): Fresh *Citrus sinensis* residues, obtained from a local juice processing facility in Algeria, were processed into dried orange pulp following the procedure described by Readh et al. (2023). The citrus residues including peel, pulp, and seeds underwent to dehydration process. The material was spread in a ventilated greenhouse equipped with air extractors and exposed to direct sunlight for 72 hours. This drying method ensured adequate aeration and minimized the risk of mold development. The sun-dried material was subsequently ground using a 1 mm mesh sieve to produce a fine powder suitable for broiler feed formulation. The dried orange pulp was then stored in opaque, airtight plastic bags at a temperature of 15–22°C in a dry environment until use.

Animals, Diets and Experimental design : At the start of the trial, the brooding temperature in the experimental broiler facility was maintained at approximately 32–34 °C. Beginning on day 4, the temperature was gradually reduced by 0.5 °C per day until reaching a stable level of 20–22 °C, which was maintained for the remainder of the experiment. Relative humidity was controlled within a range of 60–70%. The birds were reared under optimal environmental and hygienic conditions. The poultry house was equipped with a thermostatically controlled ventilation system and cross-ventilation to ensure adequate air circulation. A lighting program was implemented in accordance with the *Arbor Acres* commercial broiler management guide. For the first 21 days, a 23:1-hour light-to-dark cycle was applied, followed by a 22:2-hour cycle from day 22 until day 49.

At 15 days of age, all birds were individually weighed and randomly assigned to four dietary treatment groups. Each treatment consisted of five replicates (floor pens) with 10 birds per replicate. The dietary treatments included: a control diet formulated without feed substitution, and three experimental diets in which corn was partially replaced with 5%, 10%, or 15% dried orange pulp (DOP). The composition and nutrient contents of the experimental diets are presented in Table 1.

Table 1. Ingredients and nutrients composition of different diets

	Control	DOP5%	DOP10%	DOP15%
Corn grains	67,00	62,00	57,00	52,00
Soybean meal	27,00	27,00	27,00	27,00
Wheat bran	4,00	4,00	4,00	4,00
DCP	1,00	1,00	1,00	1,00
Vit-Min Premix	1,00	1,00	1,00	1,00
Dried Orange pulp	0	5,00	10,00	15,00
Metabolizable Energy (kacl/kg)	3121.49	3140.41	3162.50	3187.45

***Vitamin-mineral premix:** Provided (in mg kgG1 of diet), Vitamin E: 6, Vitamin K3: 0.80, Vitamin B1: 1, Vitamin B2: 3, Pantothenate of Ca: 6, Vitamin B6: 1.5, Vitamin B12: 0.006, Folic acid: 0.2, Nicotinic acid: 12, Copper: 5, Cobalt: 0.65, Manganese: 65, Zinc: 65, Selenium: 0.25, Iron: 50, Iode: 0.8, Magnesium: 100. Abbreviations; EM: Metabolizable energy, C: Control diet, CO: Canola seed diet, SFA: Saturated fatty acids, MUFA: Monounsaturated fatty acids, PUFA: Polyunsaturated fatty acids, **DCP:** Calcium + Phosphore, **ME:** Metabolizable Energy.

Sampling and Data Collection

Performance Measurement: Body weight (BW) and feed conversion ratio (FCR) were measured during each phase of the rearing period. Each treatment group consisted of 10 broiler chickens. Feed intake and body weight data were used to calculate FCR as the ratio of feed consumed to body weight gain.

Slaughter Measurements: After 49 days of rearing, ten birds per group were randomly selected based on the average weight of the group and slaughtered. After 8 hours of fasting for total stomach evacuation, these animals were used for measuring carcass yield. Various parts of the carcasses were dissected and weighted separately. The collected carcass parts included liver, and abdominal fat. The relative weights of these organs were also expressed as a percentage of live body weight. Carcass yield was calculated by subtracting eviscerated (liver, heart, gizzard and spleen) weight from the carcass weight.

Stastical Analysis

For determination of the statistical significance of the results, appropriate parametric test ANOVA were used. The results were presented as text and tables as mean values and standard error of mean (SEM). Data were statistically analyzed by SPSS statistical software (IBM SPSS version 26). The statistical comparison was made by Tukey test at the 95% probability level.

Results and Discussion

The results of the experimental trial on broiler performance, and carcass characteristics are summarized in Tables 2–4.

Table 2 presents the effects of incorporating varying levels of dried orange pulp into broiler diets on growth performance parameters, including body weight (BW) and feed conversion ratio (FCR), throughout the rearing period. Broilers fed diets containing 5%, 10%, and 15% DOP exhibited improved body weights by day 49 compared to those in the control group. Notably, the 5% DOP group showed an increase in live body weight of over 12% relative to the control group at the end of the rearing period.

In terms of feed efficiency, the inclusion of DOP led to a reduction in FCR values. Specifically, FCR decreased by approximately 6% and 9% in the 5% and 10% DOP groups, respectively, when compared to the control.

Table 2. Effect of dried orange pulp on the performance of broiler chickens

Item	**Treatments**				**SEM**	**p value**
	Control	**5% DOP**	**10% DOP**	**15% DOP**		
Starter period of Postnatal 1st–21st day						
BW (g/chick/duration)	715^{a}	850^{c}	830^{bc}	785^{a}	17.26	0.00002
FCR	1.15^{bc}	1.05^{a}	1.10^{ab}	1.20^{c}	0.12	0.00009
Grower period of Postnatal 21st–35st day						
BW (g/chick/duration)	1920^{bc}	1960^{b}	1925^{bc}	1910^{a}	19,72	0,07
FCR	1.65^{a}	1.70^{a}	1.95^{a}	1.85^{a}	0.41	0.10
Finisher period of Postnatal 35st–49st day						
BW (g/chick/duration)	2905^{a}	3325^{c}	3075^{bc}	3005^{b}	29.94	0.00015
FCR	2.50^{a}	2.35^{a}	2.25^{a}	2.40^{a}	0.22	0.16

^{abc} Means in each column with no common superscript differ significantly at ($p < 0.05$). (n=10).
Abbreviations: BW: body weight, FCR: feed conversion ratio, SEM**:** standard error of the means
DOP: Dried Orange Pulp

Although no statistically significant differences were observed during the finisher phase (35–49 days), broilers fed DOP diets demonstrated numerically better FCR values, indicating enhanced feed efficiency.

Overall, the incorporation of dried orange by-products contributed to improved body weight gain and feed utilization in broiler chickens.

Table 2. Effect of dried orange pulp on the performance of broiler chickens

Item	Treatments				SEM	p value
	Control	5% DOP	10% DOP	15% DOP		
Carcass yield (%)	76.7^{a}	75.7^{a}	73.3^{a}	78.5^{a}	2.66	0.16
Abdominal fat (%)	1.12^{c}	0.97^{b}	0.96^{b}	0.82^{a}	0.15	< 0.001
Liver yield (%)	2.30^{a}	2.32^{a}	2.35^{a}	2.85^{b}	0.13	0.0005

^{abc} Means in each column with no common superscript differ significantly at (P < 0.05). (n=10).
Carcass yiled % : percentage relative to the whole carcass, abdominal and liver yield % were relative to carcass.
SEM**:** standard error of the means
DOP: Dried Orange Pulp

Eviscerated Carcass Weight and Yield: showed no significant differences (P = 0.057).
Abdominal Fat Yield: was lower in broilers fed dried orange by-products compared to controls (P < 0.001). Control chickens had 1.12% abdominal fat relative to eviscerated weight, whereas those fed 15% DOP showed a 22% reduction.
Liver Yield: broilers in the 10% and 15% DOP groups exhibited significantly higher liver yields than controls (P < 0.05). The average liver weight in the 15% DOP group increased by ~25% compared to controls. Additionally, liver yield (% of carcass) rose proportionally with dietary DOP inclusion, highlighting its stimulatory effect on hepatic tissue mass, particularly at the highest inclusion level.

Discussion

Our findings align with those of Parobali et al. (2024), who reported significant improvements in body weight gain and feed conversion ratio (FCR) in broilers fed 0.25%, 0.5%, and 0.75% *Citrus sinensis* seed at days 21 and 49. Similarly, Ahmad et al. (2024) found that supplementing quail broiler diets with 0.5, 1, and 1.5 mL/kg of dried *C. sinensis* peel methanolic extract improved FCR and weight gain, with the DCSP1.5 group showing the best performance.
Our results are consistent with those of Vlaicu et al. (2020), who reported significant improvements in broiler growth and FCR following supplementation with orange pulp or *Citrus sinensis* essential oil. The enhanced FCR observed in our 5% DOP group during days 1–21 and 35–49 aligns with findings by Abbasi et al. (2015), where dried orange pulp positively influenced weight gain. Improvements at 5% and 10% inclusion levels may be attributed to the high content of soluble carbohydrates, organic acids, and bioactive flavonoids (e.g., hesperidin, naringin), known to promote digestive enzyme activity and gut health (Kamboh and Zhu, 2013; Jiang et al., 2020). Ahmad et al. (2024) also linked weight gain to the citric acid in orange peel, which, through its antimicrobial action and low pH, suppresses harmful gut microbes, reduces toxicity, improves protein digestion and energy utilization. Our findings align with Pourhossein et al. (2015), who reported a significant increase in liver weight following the addition of orange peel essential oil to broiler diets. Similarly, Goliomytis et al. (2015) observed increased liver yield in broilers fed orange pulp-based diets rich in naringin. The reduction in abdominal fat in our study corroborates results from Abd El Latif et al. (2023) and Ahmed (2022), who found that dried lemon pulp supplementation (0.5–1%) lowered fat deposition. Likewise, Abbasi et al. (2015) and Ebrahimi et al. (2014) showed that dried orange residues and orange peel extract reduced abdominal fat. Naringin, a citrus flavanone, may modulate lipid metabolism and reduce fat accumulation (Guo et al., 2016), while organic acids such as citric acid enhance lipid metabolism (Fik et al., 2021) and lower intestinal pH, potentially influencing fat storage (Pourhossein et al., 2012). Moreover, fruit-derived flavones reduced abdominal adipose tissue weight (Ma et al., 2015), although Basir and Toghyani (2017) found no significant effect with dried lemon pulp.
Croze et al. (2015) proposed that citrus compounds may reduce fatty acid synthesis in adipose tissue. Polyphenols inhibit lipase activity (Kang et al., 2012), hepatic lipogenesis (Saha et al., 2019), and fat absorption. Phytosterols also exert hypolipidemic effects by modulating lipid metabolism in hepatocytes (Dossou et al., 2018; Kesbiç et al., 2020). Furthermore, AMPK activation inhibits lipogenesis by downregulating fatty acid synthase, serving as a metabolic regulator for energy homeostasis (Pu et al., 2012).

Acknowledgements

This manuscript was obtained from the Thesis of CHAIB EDDOUR Ahmed Readh at Agronomy Higher School Mostaganem, Algeria. We are grateful to Biotechnology applied to Agriculture and Environmental Preservation in the Agronomy Higher school Mostaganem, Algeria and Mrs LITIM Miloud and Mr BOUDEROUA Kaddour for support.

References

Abbasi H, Seidavi A, Liu W, Asadpour L (2015) Investigation on the effect of different levels of dried sweet orange (Citrus sinensis) pulp on performance, carcass characteristics and physiological and biochemical parameters in broiler chicken. Saudi JBio lSci22 :139–146. https://doi.org/10.1016/j.sjbs.2014.09.006

Abd El Latif, M. A., Abdel-Wareth, A. A., Daley, M., & Lohakare, J. (2023). Effect of Dietary Orange Peel Meal and Multi-Enzymes on Productive, Physiological and Nutritional Responses of Broiler Chickens. Animals, 13(15), 2473. https://doi.org/10.3390/ani13152473

Ahmad, F., Sultan, A., Khan, S., Ali, M., Ali, I., Abdullah, H., ... & Swelum, A. A. (2024). Effect of citrus peeling (*Citrus sinensis*) on production performance, humoral immunity, nutrients, and energy utilization of broiler quails. Poultry Science, 103(1), 103207; https://doi.org/10.3390/ani10071209

Ahmed, S. T. (2022). 3. Evaluating the Effects of Dried Orange and Lemon Peel on Growth Performance and Meat Quality of Broilers. Journal of Agriculture, Food and Environment (JAFE)| ISSN (Online Version): 2708-5694, 3(2), 11-16. DOI: https://doi.org/10.47440/JAFE.2022.3203

Alzawqari, M. H., Al-Baddany, A. A., Al-Baadani, H. H., Alhidary, I. A., Khan, R. U., Aqil, G. M., & Abdurab, A. (2016). Effect of feeding dried sweet orange (*Citrus sinensis*) peel and lemon grass (Cymbopogon citratus) leaves on growth performance, carcass traits, serum metabolites and antioxidant status in broiler during the finisher phase. Environmental Science and Pollution Research, 23(17), 17077-17082. https://doi.org/10.1007/s11356-016-6879-7

Basir, R., & Toghyani, M. (2017). Effect of dietary graded levels of dried lemon (*Citrus aurantifulia*) pulp on performance, intestinal morphology, and humoral immunity in broiler chickens. International Journal of Recycling of Organic Waste in Agriculture, 6(2), 125-132. https://doi.org/10.1007/s40093-017-0159-5

Croze, M.L.; Géloën, A.; Soulage, C.O. Abnormalities in myo-inositol metabolism associated with type 2 diabetes in mice fed a high-fat diet: Benefits of a dietary myo-inositol supplementation. Br. J. Nutr. 2015, 113, 1862–1875. https://doi.org/10.1017/S000711451500121X

Dossou S, Koshio S, Ishikawa M, Yokoyama S. 2018. Growth performance, blood health, antioxidant status and immune response in red sea bream (*Pagrus major*) fed Aspergillus oryzae fermented rapeseed meal (RM-Koji). 75: 253–262. https://doi.org/10.1016/j.fsi.2018.01.032

Ebrahimi, A., Qotbi, A. A. A., Seidavi, A., & Bahar, B. (2014). The effects of dietary supplementation of *Citrus sinensis* peel extract on production and quality parameters of broiler chicken. Journal of Applied Animal Research, 42(4), 445-450. https://doi.org/10.1080/09712119.2013.875916

Fik M, Hrnčár C, Hejniš D, Hanusová E, Arpášová H and Bujko J (2021). The Effect of Citric Acid on Performance and Carcass Characteristics of Broiler Chickens. Anim. Sci. Biotech. 54 (1): 187-192.

Goliomytis, M.; Kartsonas, N.; Charismiadou, M.A.; Symeon, G.K.; Simitzis, P.E.; Deligeorgis, S.G. The influence of naringin or hesperidin dietary supplementation on broiler meat quality and oxidative stability. PLoS ONE 2015, 10, e0141652. https://doi.org/10.1371/journal.pone.0141652

Guo, X., Liu, J., Cai, S., Wang, O. and Ji, B. (2016). Synergistic interactions of apigenin, naringin, quercetin and emodin on inhibition of 3T3-L1 preadipocyte differentiation and pancreas lipase activity. Obes. Res. Clin. Pract. 10: 327-339. https://doi.org/10.1016/j.orcp.2015.08.004

Jiang, X., Li, A., Wang, Y., Iqbal, M., Waqas, M., Yang, H., ... & Li, J. (2020). Ameliorative effect of naringin against thiram-induced tibial dyschondroplasia in broiler chicken. Environmental Science and Pollution Research, 27(10), 11337-11348. https://doi.org/10.1007/s11356-020-07732-5

Kamboh, A. A., and W. Y. Zhu. 2013. Effect of increasing levels of bioflavonoids in broiler feed on plasma anti-oxidative potential, lipid metabolites, and fatty acid composition of meat. Poult. Sci. 92:454–461. https://doi.org/10.3382/ps.2012-02584

Kang, M. I., A. Kobayashi, N. Wakabayashi, S. G. Kim, and M.Yamamoto. 2004. Scaffolding of Keap1 to the actin cytoskeleton controls the function of Nrf2 as key regulator of cytoprotective phase 2 genes. Proceedings of the National Academy of Sciences of the United States of America 101 (7):2046–51. https://doi.org/10.1073/pnas.0308347100

Kesbic¸ OS, Parrino V, Acar U, Yilmaz S, Paro GL, Fazio F. 2020. Effects of Monterey Cypress (*Cupressus macrocarpa Hartw*) leaf essential oil as a dietary supplement on growth performance and haematological and biochemical parameters of common Carp (*Cyprinus Carpio L.*). Ann Anim Sci. 20(4):1411–1426. https://doi.org/10.2478/aoas-2020-0041

Lagha-Benamrouche, S., Madani, K. (2013). Phenolic contents and antioxidant activity of orange varieties (*Citrus sinensis L.* and *Citrus aurantium L.*) cultivated in Algeria: Peels and leaves. Ind. Crop. Prod. 50: 723-730. https://doi.org/10.1016/j.indcrop.2013.07.048

Ma, J. S., Chang, W. H., Liu, G. H., Zhang, S., Zheng, A. J., Li, Y., et al. (2015). Effects of Flavones of Sea Buckthorn Fruits on Growth Performance, Carcass Quality, Fat Deposition and Lipometabolism for Broilers. Poult. Sci. 94 (11), 2641–2649. https://doi.org/10.3382/ps/pev250

Nieto, G., Fernández-López, J., Pérez-Álvarez, J. A., Peñalver, R., Ros, G., & Viuda-Martos, M. (2021). Valorization of citrus co-products: Recovery of bioactive compounds and application in meat and meat products. Plants, 10(6), 1069. https://doi.org/10.3390/plants10061069

Parobali, T., Adjei-Mensah, B., Songuine, T., Yarkoa, T., Karou, S. D., & Eklu-Gadegbeku, K. (2024). Influence of Citrus Sinensis seed powder on growth performance, morphological and histological development of the small intestine of broiler chickens. Journal of Applied Poultry Research, 33(2),100395. https://doi.org/10.1016/j.japr.2023.100395

Pourhossein Z, Qotbi AAA, Seidavi A. 2012. Investigation on the effects of different levels of *Citrus sinensis* peel extract on gastrointestinal microbial population in commercial broilers. Afri J Microbiol Res. 6:6370–6378. https://doi.org/10.5897/AJMR12.828

Pourhossein, Z., Qotbi, A. A. A., Seidavi, A., Laudadio, V., Centoducati, G., & Tufarelli, V. (2015). Effect of different levels of dietary sweet orange (*Citrus sinensis*) peel extract on humoral immune system responses in broiler chickens. Animal Science Journal, 86(1), 105-110. https://doi.org/10.1111/asj.12250

Pu P, Gao DM, Mohamed S, Chen J, Zhang J, Zhou XY, Zhou NJ, Xie J, Jiang H. 2012. Naringin ameliorates metabolic syndrome by activating AMP-activated protein kinase in mice fed a high-fat diet. Arch Biochem Biophys. 518:61–70. https://doi.org/10.1016/j.abb.2011.11.026

Readh, C. E. A., Miloud, L., Abdelkarim, L., Kaddour, B., & Chaima, B. (2023). Effect of graded levels of dried orange (Citrus sinensis) byproducts on production efficiency, blood parameters and antioxidant status of broiler chickens. Asian Journal of Dairy and Food Research, 42(3), 314-319. https://doi.org/ 10.18805/ajdfr.DRF-307

Saha P, Talukdar AD, Nath R, Sarker SD, Nahar L, Sahu J, Choudhury MD. 2019. Role of natural phenolics in hepatoprotection: a mechanistic review and analysis of regulatory network of associated genes. Front Pharmacol. 10: 509–534. https://doi.org/10.3389/fphar.2019.00509

Seidavi, A. R., Azizi, M., Ragni, M., Laudadio, V., & Tufarelli, V. (2018). Practical applications of agricultural wastes in poultry feeding in Mediterranean a Middle East regions. Part 2: tomato, olive, date, sunflower wastes. World's Poultry Science Journal, 74(3), 443-452. DOI: https://doi.org/10.1017/S004393391800051X

Vlaicu, P.A.; Untea, A.E.; Panaite, T.D.; Turcu, R.P. Effect of dietary orange and grapefruit peel on growth performance, health status, meat quality and intestinal microflora of broiler chickens. Ital. J. Anim. Sci. 2020, 19, 1394–1405. https://doi.org/10.1080/1828051X.2020.1845576

Assessing the Labor Dynamics, Market Demand, and Strategic Challenges in Domestic Tea Industry: (A Case of Central Sri Lanka)

R.A.G.U. Ranasinghe

School of Public Administration, University of Electronic Science and Technology of China.

Abstract

The tea industry is a cornerstone of Sri Lanka’s economy, and its domestic market faces unique challenges and opportunities for growth. This study investigates the dynamics of labor, financial, and strategic factors affecting tea brand marketing within Sri Lanka's Kadugannawa region, located in the Central Province. The research focuses on the key challenges, including labor shortages, financial constraints, market competition, and strategic inefficiencies, which hinder the growth of local tea brands. In addition, the study highlights significant opportunities for growth, such as rising domestic demand, the adoption of more effective marketing strategies, and product diversification. Through a case study approach, this research provides a detailed analysis of the factors influencing the local tea market and offers recommendations for stakeholders to optimize marketing efforts, improve brand positioning, and enhance overall market performance. The findings contribute to a deeper understanding of the evolving dynamics of the tea industry in Sri Lanka and propose strategies for leveraging existing opportunities to strengthen the domestic market presence of Sri Lankan tea brands.

Key words: *Financial constraints, Market competition, Marketing strategies, Product diversification, Brand positioning.*

Introduction

Sri Lanka has long been known for producing some of the finest tea in the world, with its tea estates spread across the lush hills of the Central Province. However, while Sri Lankan tea enjoys international fame, the domestic tea market faces a unique set of challenges. The complexities surrounding labor conditions, financial limitations, and strategic marketing decisions significantly impact the growth potential of local tea brands. As the global tea market continues to shift towards more niche and premium offerings, understanding how these factors interact on a local level is crucial for the future of Sri Lanka’s domestic tea industry.

The dynamics of labor, financial resources, and strategic positioning play a crucial role in the growth prospects of domestic tea brands in Sri Lanka. Labor-related issues, such as wage disparities and labor shortages, remain a central challenge (Pereira & Silva, 2019). Financially, the capital requirements for expanding and marketing domestic tea brands often exceed what small-scale producers can manage, thereby limiting their growth potential (Bandara & Wijesundara, 2020). Moreover, strategic factors such as branding, marketing, and market segmentation have not been fully optimized by many local producers, who continue to rely on traditional methods and lack the innovation needed to capture both local and global markets effectively (Wijesundara & Jayantha, 2018). Although various studies have explored the tea industry from a macroeconomic perspective, there remains a gap in research that specifically addresses the strategic, labor, and financial challenges faced by domestic tea brands in Sri Lanka. Previous research has predominantly focused on large-scale production or export strategies (Kumarasinghe & Rajapakse, 2021), with limited attention given to the domestic market dynamics. Furthermore, few studies have examined the opportunities for growth by leveraging local resources, labor practices, and financial structures (Fernando & Abeywardena, 2017). This study aims to fill this gap by offering an in-depth analysis of the conditions and challenges specific to domestic tea branding in Sri Lanka. The significance of this research lies in its potential to inform policymakers, local tea producers, and marketers about the strategic interventions needed to enhance the domestic tea market. It could offer insights into labor policy reforms, financial mechanisms for small producers, and strategic marketing practices that can foster a more robust domestic tea industry. By identifying areas for improvement, this study may contribute to the sustainable growth of local tea brands and a more diversified domestic market.

Methodology

This study employed a mixed-method design, where both qualitative and quantitative data was collected and analyzed simultaneously but independently, and then integrated for a more comprehensive understanding of the research problem.

Quantitative Data Collection: structured questionnaires were developed and distributed to key stakeholders in Sri Lanka’s domestic tea industry, including tea producers, brand managers, marketers, and industry experts. The questionnaires focused on several critical areas: labor dynamics, such as experience and skills level; financial dynamics, including pricing strategies, and financial constraints faced by tea producers; strategic factors like marketing strategies, brand positioning, distribution channels, and the level of competition in the market; and opportunities for growth, which explored future market trends, potential areas for investment, and the scope for product diversification. Valuable quantitative insights into the key drivers of the tea industry were provided by these questionnaires, forming a solid foundation for understanding its current performance and growth prospects.

Qualitative data collection: in-depth, semi-structured interviews were conducted with a range of stakeholders, including tea producers, factory owners, and retailers/distributors involved in the domestic tea market. The interviews focused on several key areas such as labor challenges and their impact on production quality, financial constraints and investment challenges, strategic decision-making in marketing and competition, and perceived opportunities for growth and innovation in the market. Valuable insights were gained through these interviews, shedding light on the complexities and dynamics of the domestic tea industry.

Sample size

It is not possible for every member of the entire population to be studied, measured, and recommends that a sample be studied and goes ahead to define a sample as a sub- set of study populations used in research (Kazerooni, 2001). The target population for the study comprised Sales, marketing, production and support department staff, Managers of the company, Wholesalers and retailers. The sample size of this study was 60, which included 30 company employees and 30 wholesalers and retailers.

Data Analysis Techniques

Quantitative data were analyzed through descriptive statistics, including frequency distributions and percentages, to summarize trends and patterns across different variables such as labor dynamics, financial challenges, and market demand. This allowed for a clear presentation of the respondents' views on the current state of the tea industry. Additionally, comparative analysis was employed to examine the relationships between different factors, such as the demand and supply of various tea brands, and to assess the impact of external factors like the pandemic. The qualitative data, obtained from semi-structured interviews, were analyzed using thematic analysis to identify key themes and insights regarding the challenges faced by stakeholders, such as communication barriers and the lack of skilled labor. Both data sets were integrated to provide a holistic view of the industry's dynamics, enabling the identification of opportunities and areas for improvement in the domestic tea market.

Results And Discussion

Labor composition of Employees and their impact on Organizational Structure

The distribution of employees based on their years of experience in the tea industry was found to provide valuable insights into the workforce dynamics of Sri Lanka's domestic tea brand market. It was found that 50% of employees had 10 years or less of industry experience, highlighting a workforce that was relatively young. It was suggested that this younger workforce might bring fresh perspectives and innovation to the industry, which was considered vital for staying competitive in both local and global markets. In contrast, only 10% of employees had over 30 years of experience, indicating a small but highly experienced segment. It was recognized that these long-tenured employees possessed valuable knowledge and expertise, particularly in traditional methods of tea production and brand development. This duality in workforce experience—young and innovative versus seasoned and knowledgeable—was seen to create a balanced labor dynamic, essential for both sustaining traditional practices and driving future growth and strategic evolution in the industry. In terms of occupational roles, the majority of employees were positioned as Officers, Supervisors, and Production Managers, roles that were recognized as critical to the operational structure within the tea industry. These roles were considered essential in influencing both the production processes and strategic management of domestic tea brands in Sri Lanka. All selected respondents were involved in the survey, ensuring that the data collected offered a representative view of the employee landscape within the sector.

Table 1: Number of years in business

Number of years in business	Frequency	Percentage
00-10	15	50%
11-20	08	27%
21-30	04	13%
31-40	03	10%

Demand for the tea within past few years and supply to the demand

The data collected on the demand for tea within the past few years (Table 2) revealed a clear trend of increasing consumer demand. Out of 30 respondents, 87% (26 respondents) agreed that the demand for tea had increased, while 13% (4 respondents) partially agreed. The overwhelming majority of respondents indicated a growing demand for tea in Sri Lanka, which was aligned with trends in the global and local beverage market. Factors such as tea's health benefits and its position as a traditional beverage in Sri Lankan culture were cited as key drivers for this increase. Moreover, the perception that the demand would continue to rise suggested a positive outlook for the industry in the coming years. Another notable point was the increased sensitivity of consumers to price, quality, and convenience. It was emphasized by respondents that consumers were now more discerning in their choice of tea, balancing both price and quality, alongside considerations of health benefits and ease of access. The growing emphasis on convenience suggested that tea was preferred to be purchased from locations that were more easily accessible, indicating a shift toward convenience-oriented consumption patterns.

The data regarding the supply-side capacity to meet the growing demand for tea (Table 3) presented a different picture. When asked if there was a good supply to meet the demand, only 24% (7 respondents) agreed, while 10% (3 respondents) partially agreed. On the other hand, a significant 47% (14 respondents) partially disagreed, and 20% (6 respondents) neither agreed nor disagreed. The majority of respondents, especially those working within the tea industry, felt that there was a gap between the increasing demand and the supply's ability to meet it. Key reasons for this discrepancy were raised as low production levels and inadequate distribution channels. These factors were likely hindering the industry's capacity to fully capitalize on the growing demand. The issues raised around low production levels were thought to point to constraints such as limited access to resources, outdated production techniques, or insufficient investment in scaling up operations. Furthermore, the lack of adequate distribution channels was suggested to indicate that improving logistics and expanding the availability of tea in both urban and rural markets could be vital in addressing these supply-side challenges.

Valid	Number	Percentage
Agree	26	87%
Partially agree	04	13%

Table 2: Tea demand has increased within past few years

Table 3: There is a good supply to the demand

Valid	Number	Percentage
Agree	07	24%

Partially Agree	03	10%
Neither agree nor disagree	06	20%
Partially Disagree	14	47%

Pandemic Impact on the Tea Industry

The COVID-19 pandemic created a range of challenges for the tea industry, affecting both the local and international markets. Transport routes were disrupted, production was impacted, and market conditions were altered, leading to significant economic consequences. Half of the respondents (50%) agreed that transport routes were blocked due to the pandemic, significantly impacting their ability to sell tea. Small-scale businesses, in particular, were affected as they depend on transportation for distribution. The lockdown measures and restrictions led to the inability to access remote markets, resulting in lower sales for these businesses. Additionally, 37% partially agreed with the statement, suggesting that some respondents had experienced transport issues to a certain extent. Only 13% disagreed with the idea that transport routes had been blocked, citing that they had been able to operate without significant disruptions. This may reflect the experience of larger businesses that were granted permission to continue selling directly to consumers during the pandemic, a privilege not always extended to small-scale vendors.

A significant 40% of respondents agreed that production had been directly impacted by the pandemic. Restrictions on labor, limited access to raw materials, and disruptions in the supply chain likely contributed to the decrease in production levels. Additionally, 43% partially agreed with this statement, indicating that while production had been affected to some degree, some operations had been able to continue under modified conditions. Only 17% of respondents neither agreed nor disagreed, suggesting that these respondents either had had limited exposure to production disruptions or had operated under less stringent conditions during the pandemic. Only 10% of respondents agreed that import and export restrictions had created uncertainty in the market. This suggests that the disruption in international trade was not perceived as a major factor for all participants. However, the majority of respondents (57%) partially agreed with this view, indicating that the uncertainty surrounding the global market had affected their business operations to some extent. A further 33% neither agreed nor disagreed, suggesting that these respondents either had not felt the impact of these restrictions or had not had sufficient information to evaluate them. The findings suggest that the pandemic had significantly impacted the tea industry in Sri Lanka, with disruptions to transport, production, and trade causing notable setbacks for businesses. The local market, particularly small-scale tea producers, had been hit hardest by these disruptions, while larger businesses with more resources had been somewhat better positioned to adapt to the circumstances.

Table 4: Transport routes were blocked due to pandemic

Valid	**Number**	**Percentage**
Agree	15	50%
Partially Agree	11	37%
Strongly Disagree	04	13%

Table 5: Production was affected due to pandemic

Valid	Number	Percentage
Agree	12	40%
Partially Agree	13	43%
Neither agree nor disagree	05	17%

Table 6: Import and export restrictions created uncertainty in market

Valid	Number	Percentage
Agree	03	10%
Partially Agree	17	57%
Neither agree nor disagree	10	33%

Key Challenges in the Sri Lankan Tea Industry

The findings from the respondents (table 7) reveal several critical challenges that employees in the tea industry are currently facing, particularly within the context of small-scale businesses and the impacts of recent economic disruptions. Communication barriers were identified as a concern by 27% of respondents, primarily from small-scale businesses, due to technological and organizational limitations. It was highlighted that these smaller businesses, lacking advanced communication technologies, face challenges in fully utilizing diverse marketing channels. Despite the industry's efforts to diversify its marketing strategies through digital and traditional methods, a disparity in communication infrastructure remained. Consequently, it was suggested that capacity building for smaller enterprises was essential to improve their communication efficiency and adapt to market demands.

Financial strain was acknowledged as a significant challenge by 81% of respondents, with the pandemic and economic crisis in Sri Lanka contributing to a decrease in tea production and exports. Small-scale businesses, particularly, were found to struggle with operational limitations, which restricted their ability to invest in necessary improvements such as technological upgrades and workforce training. A shortage of skilled labor was also recognized as a primary concern, especially among smaller businesses, due to financial constraints and the migration of workers to higher-paying industries. However, it was noted that the issue of customer preference identification was less significant, as most businesses had adopted effective market research practices and maintained well-structured customer databases.

Problem	Agree	Partially Agree	Neither Agree nor Disagree	Partially Disagree	Strongly Disagree
Poor communication channels	27%	20%	10%	37%	6%

Table 7:

Difficulties in identify customer preference	10%	10%	03%	57%	20%
Financial Issues	34%	47%	03%	16%	00%
Inaccurate data base of customers	06%	10%	07%	50%	27%
Lack of skilled labors	46%	43%	01%	10%	00%

Marketing Strategies and Their Impact on Business Success

Effective marketing strategies are pivotal to the success of any business, as they help to attract and retain customers, increase brand visibility, and drive sales. The findings indicate that the majority of companies, regardless of size, have developed marketing plans tailored to their specific needs. These strategies often include promotional tactics such as advertising, discounts, and bonuses, which are employed to enhance customer engagement and drive sales. Medium and large-scale businesses, in particular, tend to utilize a broader range of promotional activities, leveraging their larger budgets and resources to reach a wider audience. These tactics not only help in building brand recognition but also enable these businesses to maintain a competitive edge in the marketplace.

In contrast, small-scale businesses face significant challenges in implementing comprehensive marketing strategies due to limited financial resources and restricted access to funding. As a result, these businesses often struggle to carry out extensive promotional activities, which can hinder their ability to effectively promote their products and attract customers. Despite these limitations, it was observed that all companies, regardless of size, engage in both retail and wholesale distribution. Selling to wholesalers was seen as advantageous for reducing processing time and costs, while selling to retailers was recognized for its potential to broaden customer bases and enhance consumer preference. This dual approach to sales channels reflects a strategic effort to maximize market reach and improve profitability, albeit with varying levels of resource allocation depending on the scale of the business.

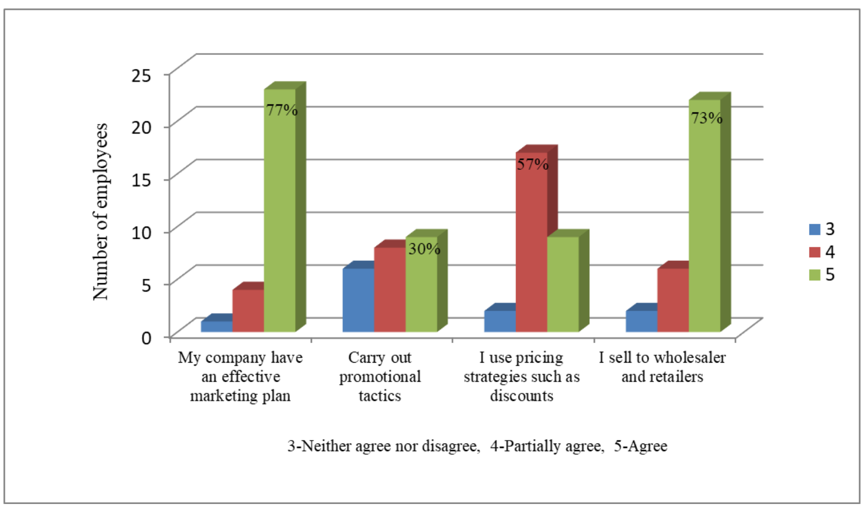


Figure 1: Marketing strategies

Wholesalers and Retailers: Business Size and Experience

The data regarding the distribution of business size among wholesalers and retailers indicates a predominance of small-scale businesses, which make up 47% of the total sample. A significant portion of these small-scale businesses is comprised of retail shops. In contrast, medium-scale businesses account for 30% of the respondents, with many of them operating both wholesale and retail functions. Large-scale businesses were represented by only 23% of the respondents, and the majority of these larger operations were wholesalers. This distribution underscores the essential role played by small and medium-scale businesses in the tea industry, as they form the backbone of the retail sector, while large-scale businesses dominate wholesale activities.

When considering the experience level of these businesses, it is evident that a substantial number have been operating for several decades. Thirty percent of the respondents reported having over 30 years of experience in the business, indicating a deep-rooted presence in the industry. However, it is notable that fewer businesses have surpassed 40 years of operation, with less than 10% falling into this category. The data suggests that while the industry is dominated by businesses with considerable experience, there is a noticeable shift towards younger businesses, particularly in the 0–30-year range, which collectively represent a majority of the respondents. This trend may reflect both the evolving market dynamics and the challenges faced by newer businesses in terms of competition and market adaptation.

Table 8: Business size

Business size	**Number**	**Percentage**
Small scale	14	47%
Medium scale	09	30%
Large scale	07	23%

Table 9: Number of years in business

Years	**Number**	**Percentage**
0-10	05	17%
11-20	07	23%
21-30	07	23%
31-40	09	30%
41-50	02	07%

Tea Demand and Supply: Analysis of Popular Brands

The demand for tea in the market was assessed through the evaluation of three popular tea brands: Zesta, Laojee, and Thalawakale. The findings suggest that both Zesta and Laojee have experienced an increase in demand, with Zesta leading the market. Thirty-three percent of respondents agreed that the demand for Zesta has increased, and 57% partially agreed. This growing demand for Zesta is attributed to its product quality and convenience, as it is available in both tea packets and tea bags, offering better brewing ability and user-friendliness. In comparison, Laojee's demand has also risen, though less significantly, with 40% of respondents agreeing and 23% partially agreeing. Zesta was viewed as having a greater market appeal than Laojee, with 37% of respondents indicating a preference for Zesta over Laojee. In contrast, Thalawakale tea showed a decline in demand, with a notable 63% of respondents neither agreeing nor disagreeing regarding its increasing demand, indicating a stagnant or diminishing trend. Product-related inconveniences were cited as a key reason for this decrease in demand.

When analyzing the supply of these tea brands, the data reveals that Laojee has a stronger supply chain than the other two brands. A majority of respondents (60%) agreed that Laojee has a better supply, followed by Zesta at 43%. Thalawakale tea was found to lag behind in supply, with only 10% agreeing that it has a better supply. This supply chain advantage was seen as one of the contributing factors to Laojee’s sustained market presence. Furthermore, the importance of a diversified product line was emphasized, with 40% of respondents agreeing and 50% partially agreeing that a comprehensive product line is crucial for market penetration. Zesta's product line was seen as superior to Laojee's, with 33% of respondents agreeing, highlighting the competitive advantage that a diverse product range provides in attracting and retaining customers. The limited product line of Thalawakale tea, coupled with supply chain issues, were identified as primary reasons for its diminished market demand. To enhance customer loyalty and improve brand awareness, it was concluded that expanding the product line and ensuring a reliable supply chain are essential for businesses aiming to strengthen their market position.

Table 10: Demand for tea brands

	Agree	**Partially agree**	**Neither agree nor disagree**	**Partially disagree**	**Strongly disagree**
Demand for Zesta has increased	33%	57%	07%	03%	00%
Demand for Laojee has increased	40%	23%	20%	17%	00%
Demand for Talawakale tea has increased	03%	10%	63%	23%	00%
Demand for Zesta >Laojee	37%	23%	17%	23%	00%
Demand for Thalawakele > Laojee	00%	07%	27%	60%	07%

Table 11: Tea Supply and product line

	Agree	Partially agree	Neither agree nor disagree	Partially disagree	Strongly Disagree
Zesta has a better supply	43%	40%	10%	07%	00%
Laojee has a better supply	60%	33%	7%	00%	00%
Talawakale tea has a better supply	00%	10%	33%	37%	20%
Zesta has a better product line than Laojee	33%	43%	13%	07%	03%
Product line is important for market penetration	40%	50%	10%	00%	00%

Future Prospects of Tea Brands: Consumer Preferences and Brand Performance

The tea market has seen a steady increase in demand in recent years, with expectations of continued growth in the coming years. While respondents anticipate that consumers will continue to favor established brands such as Zesta, Laojee, and Thalawakale, there is uncertainty regarding the profitability of these brands moving forward. This uncertainty primarily stems from potential price increases, which could lead customers to explore cheaper alternatives or other substitute products. While respondents agree that brands with a strong customer base and established loyalty, such as Zesta and Laojee, are more likely to maintain their profitability in the future, they emphasize the importance of product development to foster customer retention and loyalty. It was widely recognized that brands which focus on enhancing convenience, quality, and innovation are better positioned to sustain demand and secure long-term profitability.

When respondents were asked to rank the tea brands based on consumer demand, Laojee emerged as the most demanded brand. This preference was largely attributed to its product convenience and competitive pricing, which have made it a popular choice among consumers. In contrast, Thalawakale tea was ranked as the least demanded brand, a result that was attributed to its inadequate supply chain and perceived lower product quality. The findings suggest that for Thalawakale to regain market traction, it must address these supply and quality issues while also considering product innovation to better meet consumer expectations. Overall, the future success of tea brands in the market will be closely tied to their ability to adapt to evolving consumer preferences, manage supply chain challenges, and continue developing products that align with customer needs.

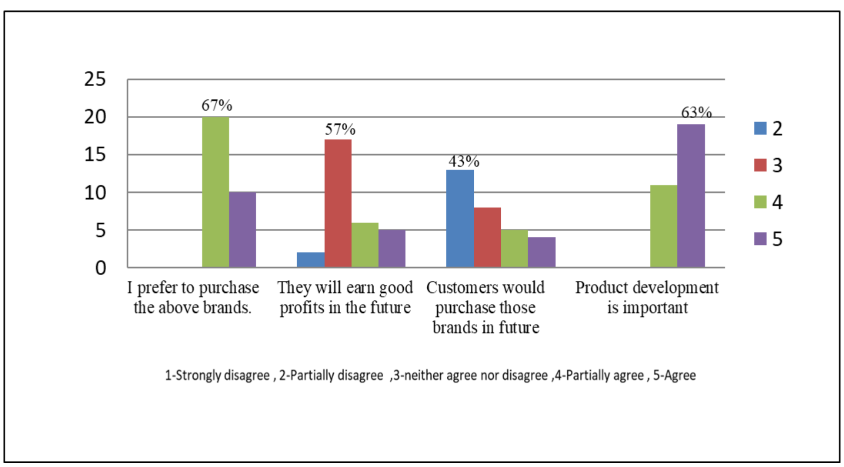


Figure 2: tea brands and their future

Conclusion and Recommendations

The study identified key challenges in Sri Lanka's tea brand marketing, primarily the lack of skilled labor and financial constraints, which hinder smaller businesses from adapting to market changes and improving marketing strategies. Additional issues such as low product awareness, insufficient product diversification, limited advertising, and fluctuating demand also affect brand performance. Intense domestic competition further complicates efforts to maintain a competitive edge.

Despite these challenges, opportunities exist, including a growing demand for tea, government support, access to labor, and the potential for more effective business management. To capitalize on these opportunities, companies should focus on investing in skilled labor development, securing financial support for small-scale businesses, diversifying products, increasing brand awareness, and leveraging government incentives. Strengthening marketing efforts through digital platforms and customer engagement will also help build brand visibility and loyalty. By addressing these strategies, tea brands can improve market performance and ensure sustainable growth.

References

Aaker, D. A. (1991). *Managing brand equity*. Free Press.

American Marketing Association. (2008). Definition of marketing and expected product quality. *Journal of Consumer Research*, 16(December), 344–353.

Anad, F., & Fattal, M. (2010). *Marketing student choice of university and marketing strategies in Syrian private higher education* (Thesis). University of Leeds, School of Education.

Ariyawardana, A. (2001). Performance of the Sri Lanka value-added tea producer. *Sri Lankan Journal of Business Economics*, 10(1), 30-42.

Bandara, S., & Wijesundara, P. (2020). Financial constraints and small-scale tea producers in Sri Lanka: Challenges and opportunities. *Sri Lankan Journal of Business Economics*, 32(1), 56-72.

Bennett, R. (2000). Life beyond the marketing mix. United Kingdom: Early Brave Publication.

Boulding, W., Lee, E., & Staelin, R. (1994). Mastering the mix: Do advertising, promotion and sales force activities lead to differentiation? *Journal of Marketing Research*, 31(May), 159–172.

Chai, W. (2009). A review of the marketing mix: 4Ps or more? *International Journal of Marketing Studies*, 1(1), 1-14.

Creveling, P. (2005). Making a case for business and marketing planning. *Rough Notes*, 137(3), 26-32.

Dare, M. (1996). *Business for high awards*. Oxford, England: Heinemann.

FAO. (2015). World tea production and trade: Current and future development—Determinants of the tea market.

Fernando, R., & Abeywardena, P. (2017). Local tea brands in Sri Lanka: A market exploration. *Journal of Marketing in Emerging Economies*, 21(2), 33-46.

Hanssens, D. M., & Gryna, F. M. (2007). Determinants of quality products: The annual monetary loss of products and processes.

Hashim, M. K. (2011). *Managing small and medium-sized enterprises: The Malaysian perspective*. UUM University Press.

Hilal, M. I. M., & Mubarak, K. M. (2016). International tea marketing and the need for reviving the Sri Lankan tea industry. *Journal of Management*, 9(1), 25–38.

Jobber, D. (2001). *Principles and practice of marketing* (3rd ed.). McGraw-Hill.

Kalu, A. (2003). International black tea market integration and price discovery.

Kerin, R. A., Hartley, S. W., & Rudelius, W. (2007). *Marketing: The core* (3rd ed.). McGraw-Hill.

Kiprotich, J. (2012). Effects of the 4Ps marketing mix on sales performance.

Kotler, P., & Connor, R. (1997). Marketing of professional services. *Journal of Marketing*, 5(4), 12-18.

Kumarasinghe, P., & Rajapakse, R. (2021). The Sri Lankan tea industry and global market strategies: Export or local focus? *Asian Economic Policy Review*, 15(4), 102-115.

Larsen, M. (2004). Quality standards in international tea markets: Challenges and consequences for tea marketing.

Lysonski, S. (2003). Should marketing managers be concerned about attitudes towards marketing and consumerism in New Zealand? A longitudinal view. *European Journal of Marketing*, 37, 385.

McCarthy, E. J. (2002). *Basic marketing*. D. Irwin.

McDonald, M. (1992). Strategic marketing planning: A state-of-the-art review. *Marketing Intelligence and Planning*, 10(4), 4-22.

McDonald, M. (1996). Strategic marketing and firm performance. *Journal of Marketing*, 2(4), 23-40.

Mela, C. F., Gupta, S., & Lehmann, D. R. (1997). The long-term impact of promotion and advertising on consumer brand choice. *Journal of Marketing Research*, 34(May), 248–261.

Muriuki, J. (2018). Labor issues and productivity in the Kenyan tea industry: Lessons for Sri Lanka. *International Journal of African Economics*, 34(1), 75-90.

Needham, A. (1996). Price strategy and market penetration.

Pereira, A., & Silva, K. (2019). Labor dynamics in Sri Lanka's tea estates: A case study of the Central Province. *Labour Studies Journal*, 45(3), 112-128.

Singh, S., & Paliwal, A. (2020). Revitalizing domestic tea brands in India: Strategic marketing approaches. *Journal of South Asian Marketing*, 10(3), 145-160.

Tanui, S., Feng, S., Shen, Z., Zeng, X., & Xinghui, L. (2005). Global tea price volatility, coping strategies, and China production. *Tea Research Institute, Nanjing Agricultural University*, China.

Thomas, A. (2012). Definition opportunity. *Business Journal*.

Wijesundara, P., & Jayantha, H. (2018). Tea branding in Sri Lanka: The road less traveled. *Journal of Strategic Marketing*, 9(2), 51-67.

Isolation and Antibiotic Resistance Profile of *Streptococcus Spp* from Commercial Poultry Carcasses in Ardabil Province, Northwest of Iran

Aidin Azizpour[1], Zahra Amirajam [2]

[1] Department of Poulry Diseases, Meshginshahr Faculty of Agriculture, University of Mohaghegh Ardabili, Ardabil, Iran.
[2] Department of Cardiology, Faculty of Medicine, Ardabil University of Medical Sciences, Ardabil, Iran
Email address: aidin_azizpour@uma.ac.ir

Abstract

Farmers use antibiotics for prophylaxis and therapy to maintain production. However, widespread use of antibiotics has increased antibiotic resistance. The present study was carried out to isolate and identify *Streptococcus spp* involved in commercial poultry carcasses and also to examine isolated bacteria for antibiotic resistance profile. Samples were taken from heart blood and liver's visceral surface of 125 carcasses obtained from 30 commercial flocks (including 27 broiler flocks, 1 laying flocks and 2 breeder flocks) located in different parts of Ardabil province, northwest of Iran. *Streptococcus spp* isolates were identified based on microbiological standard methods. The antibiotic susceptibility test was performed using the Kirby-Bauer disk diffusion method. Out of 125 collected carcasses, ninety-eight (98) bacteria isolates were identified. Among them, 6 (6.13 %) of isolates were confirmed to be *Streptococcus spp*. The strains exhibited high percentages of resistance to Ampicillin (100 %) and Doxycycline (100 %) and low percentages of resistance to Clindamycin (16.7%) and Cefatoxaime (0.0 %). Neomycin, Enrofloxacin, Erythromycin, Gentamycin, Ciprofloxacin and Chloramphenicol were resistant with 83.4 %, 83.4 %, 66.7 %, 50.0 %, 33.4 % and 33.4 %. The present study showed that poultry products, especially infectious lesions of liver and heart of poultry carcasses can be an important source of contamination and dissemination of drug-resistant *Streptococcus spp*. Therefore, performing antimicrobial sensitivity test is necessary prior to prescribing any antibiotic in commercial poultry.

Key Words: *Antibiotic resistance, Streptococcus spp, Poultry carcasses, Ardabil province*

Introduction

Broilers have a high productivity, but their level of immunity against the disease is relatively low. In order to improve the immunity of chicken, farmers usually administering vitamins, vaccinations and antibiotics. Antibiotics are often used in poultry as a prevention of disease transmission and as a growth promoter. Antibiotics are also used for the treatment [1]

In spite of its beneficial to human and animal health, as well as increased productivity over the past few years, abusive use of antibiotics has led to resistance to pathogenic and commensal bacteria. [2, 3]. Over the past 50–60 years, bacterial resistance has spread [3, 4]. It is feared that resistant bacteria in chicken can infect humans, thereby reducing the effectiveness of treatment and caused death [1, 2, 3, 4, 5, 6].

Streptococcus spp. is a normal microflora in the mucosa digestive tract of broiler chickens [3]. Cases of *Streptococcus spp*. in chicken Broilers have been widely reported, but rarely reported as outbreaks. This matter occured due to infection with *Streptococcus spp*. generally subclinical and secondary [2]. Some diseases that can be caused this Gram-positive bacteria which include pneumonia, septicemia, cellullitis, osteomyelitis, endocarditis and meningitis with a mortality rate of up to 50% [3].

The information about antibiotic resistance from this bacteria in commercial poultry of Iran is still limited.This study aligns with the overarching objectives of zoonotic disease research, emphasizing the need to monitor antimicrobial resistance in food-producing animals to assess potential spillover events. So, The aims of this study is to isolate Streptococcus spp and determine the antibiotic resistance profile of isolated bacteria from commercial poultry carcasses in Ardabil province, northwest of Iran.

Materials and Methods

Sample collection

The study was carried out on 125 carcasses obtained from 30 commercial poultry flocks (including 27 broiler flocks, 1 laying flocks and 2 breeder flocks) in different parts of Ardabil province. So that, five carcasses were randomly selected from each flock and after necropsy, the heart blood and liver's visceral surface were sampled next to the flame. Collected samples were transported to the laboratory for Streptococcus spp isolation.

Identification of *Streptococcus spp*

Sample collected using cotton swab and stored in sample tube contained phosphate buffered saline (PBS). then the samples stored in cool box and the temperature was maintained in 4 °C.
To isolate *Streptococcus spp*., sample cultured in blood agar (BA), then incubated 37 ° C for 18-24 hours. Then the results of a single colony that grows in culture in tryptone soya agar (TSA), incubated 37 ° C for 18-24 hours. Next, isolates were carried out Gram staining to determine bacterial morphology. Coloring results with The gram ositive morphology of cocci was then tested using catalase dripping 3% H2O2 in a few bacterial isolates [3, 4].

Antibiotic Susceptibility Test

To determine the antibiotic resistance of the isolates against 10 drugs commonly in the veterinary and medical fields was used qualitative disc diffusion method by Kirby Bauer procedure on Mueller-Hinton agar (Merck, Germany) in according with instructions of Clinical Laboratory Standards Institute Guidelines (CLSI) 2018. On this criterion, the organisms were classified as Resistant (R), Intermediate (I) or Susceptible (S).
Antibiotic disks, procured from Padtan Teb Company of Iran, were Ampicillin (10), Doxycycline (30), Clindamycin (30), Enrofloxacin (15), Gentamicin (10), Ciprofloxacin (5), Erythromycin (10), Chloramphenicol (30), Neomycin (30) and Cefatoxaime (5).

Result

In this study, ninety-eight (98) bacteria isolates were obtained from 125 carcasses while no bacteria were found in 34 carcasses. Out of 98 isolates, 6 (6.13 %) isolates were detected as Streptococcus spp. The frequency of resistance of Streptococcus spp isolates to ten antimicrobial agents is is as follows:
All isolates were resistant to doxycycline (100 %) and ampicillin (100 %). In 7 antibiotics, the highest resistance was found against Neomycin (83.4%) and Enrofloxacin (83.4%), followed by Erythromycin (66.7%), Gentamycin (50.0%), Ciprofloxacin (33.4%) Chloramphenicol (33.4%), Clindamycin (16.7%), respectively. No resistance to Cefatoxaime was observed within the isolate population.

Discussion

The *Streptococcus* genus consists of 104 recognized species, ranging from commensals to highly virulent pathogens. These Gram-positive bacteria are widespread in the environment, including water, soil, and the surfaces, digestive tracts, and respiratory systems of animals and humans [2, 4].
Prevalence of *Streptococcus spp* (6.13%) was observed in the current work. While Hermana et al., (2020) reported a higher prevalence (8%) [3]. In this study, *Streptococcus spp*. was resistant to ampicillin (100%) and doxycycline (87.5%) and the resistance to 7 other antibiotics ranged from 83.4 to 16.7 %. There are no resistant for Cefatoxaime for *Streptococcus spp*. *Streptococcus spp* from broiler isolates in chicken farm in West Java had experienced resistance to ampicillin (100%), chloramphenicol (87.5%), and doxycycline (0%) [3]. Similar research in Hungary mentioned *Streptococcus spp*. isolated from clinical cases of Waterfow were resistant to the antibiotic doxycycline 89.5%, amoxicillin 42.1%, enrofloxacin 26.3% and chloramphenicol 92.2% [4].
In this study, 83.4 % of isolates showed resistance against neomycin and enrofloxacin.These two antibiotics are most commonly used in poultry husbandry for prophylactic, metaphylactic and therapeutic purposes. In this study less resistance by these isolates to ciprofloxacin , chloramphenicol, clindamycin and cefatoxaime was observed as 33.4%, 33.4% , 16.7 % and o%. The reason behind less resistance of four antibiotics is not being used or very little of common use in the poultry industry of Iran.

Conclusion

In this study, 6 isolates were identified as *Streptococcus spp*. High resistance was observed against doxycycline, neomycin and enrofloxacin which are most commonly used in poultry industry. Isolates were the most susceptible to cefatoxaime and clindamycin. Therefore, performing antimicrobial sensitivity test is necessary prior to prescribing any antibiotic in commercial poultry

References

1.Agyare, C., Boamah, V.E., Zumbi, C.N., & Osei, F.B. (2018). Antibiotic use in poultry production and its effects on bacterial resistance. Antimicrobial resistance—A global threat, 33-51. doi: 10.5772/intechopen.79371.

2.Anand, U., Reddy, B., Singh, V.K., Singh, A.K., Kesari, K.K., Tripathi, P., Kumar, P., Tripathi, V., & Simal-Gandara, J. (2020). Potential Environmental and Human Health Risks Caused by Antibiotic-Resistant Bacteria (ARB), Antibiotic Resistance Genes (ARGs) and Emerging Contaminants (ECs) from Municipal Solid Waste (MSW) 3.Landfill. Antibiotics, 10:374. doi: 10.3390/antibiotics10040374.

3.Hermana, N.S.P., Nilasari. Z., Yuniarti. E., Riyanto, A., Safika, A., & Pasaribu, F.H. (2020). Antibiotic resistance profile of Staphylococcus aureus, Streptococcus spp. and Klebsiella spp. isolated form chicken farm in Bogor, Sukabumi, and Cianjur, West Java. Journal of Physics, 1430. 012021. doi:10.1088/1742-6596/1430/1/012021.

4.Kerek, A., Szabó, A., & Jerzsele. A. (2025). Antimicrobial Susceptibility Profiles of Staphylococcus aureus and Streptococcus spp. Isolates from Clinical Cases of Waterfowl in Hungary Between 2022 and 2023. Antibiotics, 12;14(5):496. doi: 10.3390/antibiotics14050496.

5.Kovács, L., Nagy, D., Könyve,s L., Jerzsele, Á., & Kerek Á. (2023).Antimicrobial Properties of Essential Oils—Animal Health Aspects. Magy. Állatorvosok Lapja. 145:497–510. doi: 10.56385/magyallorv.2023.08.497-510.

6.Suleiman, A., Zaria, L.T., Grema, H.A., & Ahmadu, P. (2013). Antimicrobial resistant coagulase positive Staphylococcus aureus from chickens in Maiduguri, Nigeria. Sokoto Journal of Veterinary Sciences, 11(1) :51-55. doi 10.4314/sokjvs.v11i1.8.

Kekik (*Thymus Sp.*) Türlerinin Türkiye'de Yayılışı Ve Kullanımı

Gülden Sandal Erzurumlu

Niğde Ömer Halisdemir Üniversitesi, Mimarlık Fakültesi, Peyzaj Mimarlığı Bölümü, Niğde
E mail:gpeyzaj@gmail.com

Özet

Dünya nüfusunun yaklaşık %60–80'i**,** yani milyarlarca insan, birinci basamak sağlık hizmetlerinde bitkisel ilaçlara başvurmaktadır. Modern tıpta reçete edilen ilaçların önemli bir kısmı, ya direkt ya da ilhamla bitkisel bileşiklerden türetilmiştir. Örneğin, salisin (aspirin) ve artemisinin (sıtma ilacı) gibi düşük toksisiteye sahip doğal ürünler temel tedavilerde kullanılmaktadır Tıbbı ve aromatik bitkiler yaşamımızda çok büyük öneme sahiptir. Tasarım alanlarında, tıbbi amaçlı ve gıda olmak üzere farklı alanlarda kullanıma sahiptir.

TAB'lar sadece sağlık alanında değil; gıda katkı maddeleri, parfüm, kozmetik, doğal boyalar ve gıda-paketleme sanayinde antimikrobiyal ve antioksidan etkileri sayesinde geniş bir kullanım alanına sahiptir. Dünya genelinde 20.000'e yakın MAP (Medicinal and Aromatic Plants, Tıbbi ve Aromatik Bitkiler) türü tanımlanmıştır ve bunların %50'den fazlası gıdada kullanılan bioyapılar olarak değerlidir. Bu türler en çok Labiate familyasında yer almaktadır. Çalışmamda, Labiateae familyasından olan *Thymus* sp. türleri değerlendirmeye alınmıştır. Thymus türleri Türkiye'nin birçok bölgesinde farklı türlerde doğal olarak yetişmektedir. Bu amaçla, Küresel ısınmaya karşı kekik (*Thymus* sp.) kullanmanın amacı, hem ekolojik uyum hem de ekonomik-sosyal fayda hakkında bilgiler verilecektir.Kekik türlerinin mevcut durumları değerlendirilerek, 2050-2070 yılları arasında gerçekleşebilecek durum hakkında senaryolar oluşturulacaktır.
***Anahtar Kelimeler*:** *Thymus* sp., Kekik, Tıbbi ve Aromatik Bitkiler, Kuraklık, Niğde

Abstract

Approximately 60–80% of the world's population—billions of people—turn to herbal medicines in primary healthcare. A significant portion of modern prescription drugs are either directly derived from or inspired by plant-based compounds. For example, natural products with low toxicity, such as salicin (aspirin) and artemisinin (an antimalarial drug), are used in primary treatments. Medicinal and aromatic plants (MAPs) hold great importance in our lives. They are utilized in design spaces, for medicinal purposes, and as food, among other applications.

MAPs are not only used in healthcare but also have a wide range of applications in food additives, perfumes, cosmetics, natural dyes, and the food-packaging industry due to their antimicrobial and antioxidant properties. Around 20,000 MAP species have been identified worldwide, and more than 50% of these are valuable as bio-structures used in food. These species are most commonly found in the Lamiaceae family.

In my study, species of the genus *Thymus*—which belongs to the Lamiaceae family—were evaluated. *Thymus* species grow naturally in various forms across many regions of Türkiye. For this purpose, the aim of using thyme (*Thymus* spp.) against global warming will be discussed, focusing on both ecological adaptation and socio-economic benefits. The current status of thyme species will be assessed, and scenarios will be developed regarding potential situations that may occur between 2050 and 2070.
Keywords: *Thymus* sp., Thyme, Medicinal and Aromatic Plants, Drought, Niğde

Giriş

Bitkisel kaynaklı doğal maddeler, özellikle tıbbi ve aromatik bitkiler (TAB), antik çağlardan beri tedavi amaçlı kullanılmaktadır. TAB, geleneksel tıpta temel bir rol oynamakta olup, kullanımına dair tarihi kayıtlar Hindistan, Çin, Mısır, Yunan, Roma ve Pers sistemlerinde 5000 yıldan daha eskiye dayanmaktadır. Ayrıca, geleneksel bitkisel tıp Amerikan, Arap ve Japon kültürlerinde de temel taşlardan biri olmuştur.

Tıbbi ve aromatik bitkiler (TAB), insanlık tarihi boyunca gıda, ilaç, kozmetik, boya ve parfümeri gibi birçok alanda kullanılmıştır (Ekor, 2014). Bu bitkiler, içerdiği etken maddeler (alkaloidler, flavonoidler, uçucu yağlar, fenolik bileşikler vb.) sayesinde hem geleneksel tıpta hem de modern farmasötik ürünlerde geniş bir kullanım yelpazesine sahiptir (WHO, 2013).
Dünya Sağlık Örgütü verilerine göre, gelişmekte olan ülkelerde nüfusun yaklaşık %80'i temel sağlık hizmetlerinde bitkisel kaynaklı ilaçlara başvurmaktadır (WHO, 2013). Bunun temel nedenleri arasında erişilebilirlik, düşük

maliyet, kültürel uyum ve yan etkilerinin genellikle sentetik ilaçlara kıyasla daha az olması sayılabilir (Rates, 2001).

Ekonomik açıdan da TAB, yüksek katma değerli tarımsal ürünler arasında yer alır. Türkiye, coğrafi konumu, iklim çeşitliliği ve floristik zenginliği sayesinde yaklaşık 12.000 takson ile dünyanın biyolojik çeşitlilik açısından en zengin ülkelerinden biridir; bunun yaklaşık 3.700'ü endemiktir (Güner et al., 2012). Kekik (*Thymus vulgaris* ve diğer türler) gibi bitkiler Türkiye'nin tıbbi ve aromatik bitki ihracatında başı çekmektedir (Bayram et al., 2010).

Ekolojik açıdan ise TAB, polinatörlerin desteklenmesi, erozyonun önlenmesi ve doğal ekosistemlerin korunması gibi birçok ekosistem hizmetine katkıda bulunur (Power, 2010). Ancak iklim değişikliği, habitat tahribatı ve aşırı toplama, bu bitkilerin doğal popülasyonlarını tehdit eden başlıca faktörlerdir (IPBES, 2019).

TAB'ların iklim değişikliğine karşı kırılganlığı değerlendirmek ve sürdürülebilir kullanım için çok boyutlu (biyolojik, sosyo-ekonomik) olarak risk değerlendirmesi ve koruma-uyum stratejilerinin entegrasyonu türlerin sürekliliği için önemli kriterlerdendir.

Türlerin gelecekte karşılaşabileceği durumlar için iklim senaryoları (yüksek emisyon dahil) oluşturulmuştur. Buna göre bazı Thymus türlerinin uygun alanlarının daralacağını; sıcaklık değişkenlerinin dağılımda belirleyici olduğu raporlanmıştır. (Hosseini ve ark. 2024).

Küresel çapta ise, TAB (Tıbbi ve aromatik bitki) ticareti, 2010–2023 verileriyle analiz edilerek piyasa trendleri, en çok ihraç edilen ürün grupları ve ticari riskler irdelenmiştir (Zamani ve ark., 2025). Alipour ve ark. (2025) ise, Su stresi ve ABA uygulamaları altında *Thymus* türlerinde metabolit ve gen ekspresyonu değişimlerini göstermişlerdir; bazı ekotiplerin kuraklığa biyokimyasal adaptasyonları belirlenmiştir. İklime bağlı dağılım değişikliği yalnızca saha varlığı değil, aynı zamanda etken madde (uçucu yağ bileşimi) açısından kalite değişiminin yanı sıra, ekonomik ve farmakolojik olarak önemli bulunmuştur.

Kekik Türlerinin Peyzaj Tasarım Çalışmalarında Kullanım Nedenleri
Kekik Türlerinin seçilmesinin nedenleri şu şekilde sıralanabilir:
İklim Değişikliğine Uyum (Adaptasyon): Kuraklığa ve yüksek sıcaklıklara dayanıklılığı, düşük su ihtiyacı ve güçlü kök sistemi sayesinde kurak peyzaj (xeriscape) uygulamalarında kullanılabilir. Böylece yeşil alanların bakımında su tasarrufu sağlanır.
Toprak erozyonunu azaltma: Kök yapısı ve yoğun örtü oluşturan formuyla toprağı korur, özellikle kurak ve eğimli arazilerde erozyon riskini düşürür (Şekil 1).

Karbon Tutma ve Biyoçeşitlilik: Kekik, odunsu gövdesi ve çok yıllık yapısı sayesinde toprakta karbon depolamasına katkıda bulunur. Arı ve kelebek gibi tozlayıcıları çekerek ekosistem hizmetlerini destekler ve iklim değişikliğinin biyoçeşitliliğe etkilerini hafifletir.

Ekonomik Dayanıklılık: Tıbbi ve aromatik yağ üretimi sayesinde çiftçilere ek gelir sağlar; iklim değişikliğiyle azalan tarımsal verim riskini azaltır. Kurak bölgelerde alternatif gelir kaynağı olarak değerlendirilebilir (yağ, kurutulmuş kekik, bitki çayı, kozmetik hammaddesi).

Kentsel Isı Adası Etkisini Azaltma: Kent parkları, refüjler ve çatı bahçelerinde kullanıldığında ısı adası etkisini azaltır**,** buharlaşma yoluyla mikro iklimi iyileştirir.
Tıbbi ve aromatik bitki türlerinin peyzaj tasarımında hem estetik hem de işlevsel katkılar sağlayan önemli bitki gruplarındandır.

Kekik Bitkilerinin Kullanım Alanları
Tematik Bahçeler ve Bitki Koleksiyon Alanları:
Aromatik bahçeler: Lavanta, biberiye, adaçayı gibi kokulu türler ziyaretçilere görsel ve duyusal deneyim sunar.
Şifalı bitki bahçeleri: Üniversiteler, botanik bahçeleri ve terapi bahçelerinde eğitim ve tanıtım amaçlı kullanılır.

Park ve Rekreasyon Alanları
Dinlenme alanlarının çevresinde kokulu bitkilerle huzurlu atmosfer oluşturulur.
Arı ve kelebekleri çekerek biyolojik çeşitliliği artırır.

Kentsel Yeşil Alanlar
Yol kenarları, refüjler ve meydanlarda düşük bakım isteyen aromatik bitkiler tercih edilir.
Kurakçıl peyzaj uygulamalarında su tüketimini azaltır.

Terapi ve Duyusal Bahçeler
Görme, dokunma ve koku duyularını uyaran tasarımlarda kullanılır.
Psikolojik rahatlama ve stres azaltma amaçlı rehabilitasyon bahçelerinde yer alır.

Erozyon Kontrolü ve Toprak Sağlığı
Kekik, lavanta gibi derin köklü bitkiler toprağı tutarak erozyonu önler.
Bazı aromatik bitkiler zararlıları uzaklaştırarak biyolojik mücadele sağlar.

Gastronomi ve Kültürel Alanlar
Restoran bahçelerinde, otel peyzajında ve çiftlik turizmi alanlarında hem görsel hem de mutfak kullanımı için yetiştirilir (Şekil 3).

Şekil 3. TAB Bitkilerinin Peyzaj Tasarımında Kullanım Alanları

Kekik türlerinin kullanım alanlarının oldukça geniş bir yelpazede yer almaktadır. Günden güne kullanım alanları genişlemektedir. Türkiye'de kekiklere olan İhtiyaçlar gözlemlendiğinde, üretim alanları ve miktarları değerlendirilmiştir. Türkiye'de kekik üretim miktarları Tablo 1' de verilmiştir.

Tablo 1: Türkiye'de kekik üretim miktarları (Anonim, 2021'den değiştirilmiştir)

Sıra No	Ürün	Çiftçi Sayısı	Üretim Alanı (Ha)	Doğadan Toplama Üretim Alanı (Ha)	Toplam Alan (Ha)	Üretim Miktarı (Ton)	İl
1	KEKİK	1	50,20	0,00	50,20	296,53	**ADIYAMAN**
2		1	0,00	0,00	0,00	0,00	**ANKARA**
3		4	407,52	655,25	1.062,77	201,34	**ANTALYA**
4		1	0,15	0,00	0,15	1,00	**AYDIN**
5		3	86,01	0,00	86,01	256,85	**BALIKESİR**
6		2	7,71	0,00	7,71	27,79	**BURDUR**
7		2	0,13	0,00	0,13	0,80	**BURSA**
8		3	0,52	0,00	0,52	1,03	**ÇANAKKALE**
9		1	0,00	285,60	285,60	0,00	**ÇORUM**
10		1	55,33	0,00	55,33	101,76	**DENİZLİ**
11		1	0,01	0,00	0,01	0,01	**ESKİŞEHİR**
12		3	0,08	0,00	0,08	0,10	**İSTANBUL**
13		12	1,08	0,00	1,08	12,91	**İZMİR**
14		1	0,01	0,00	0,01	0,04	**KAYSERİ**
15		1	0,00	0,00	0,00	0,00	**KIRŞEHİR**
16		1	0,20	0,00	0,20	0,04	**KİLİS**
17		2	0,07	0,00	0,07	0,13	**KOCAELİ**
18		7	5,20	0,00	5,20	0,85	**KONYA**
19		1	0,10	0,00	0,10	0,20	**MANİSA**
20		1	0,20	0,00	0,20	0,20	**MERSİN**
21		5	6,21	0,00	6,21	15,17	**MUĞLA**
22		1	0,03	0,00	0,03	0,05	**SAKARYA**
23		2	0,30	0,00	0,30	1,60	**ŞANLIURFA**
24		1	0,01	0,00	0,01	0,01	**TEKİRDAĞ**
TOPLAM						**918,41**	

Türkiye'de kekik üretiminin fazla olduğu iller sırasıyla Adıyaman, Balıkesir, Antalya ve Denizli illeri başta olmak üzere 24 ilde çiftçiler yetiştiricilik ile ilgilenmektedir. Toplamda ise 2021 yılında doğadan toplanan kekik miktarının 2.195 ton toplandığı, 918,41 ton kekik üretiminin gerçekleştirildiği bunun 12 tonunun ihraç edildiği bildirilmektedir Aynı yıllarda, 196,124 kg ithal edilmektedir. Kekik türlerinin ülke ekonomisine katkı sağladığı açıkça görülmektedir.

Türkiye özelinde bakıldığında, yaklaşık 500 bitki türü tıbbi amaçla kullanılır**,** bunlardan 200'ü ihracata uygundur**.** Dünya kekik (oregano) ticaretinin %80'ini Türkiye karşılamaktadır**.** Bu bitkiler kırsal alanlarda alternatif tarım ürünü olarak önemli bir ekonomi oluşturur (Anonim, 2025).

Türkiye'de yetişen ve yetiştirilen kekik türlerinin bir kısmı endemik olarak bulunmakta ve nesli tükenme tehlikesi ile karşı karşıyadır. Endemik olanların mevcut durumu değerlendirilmiş ve 2050-2070 yıllarına ait senaryolar oluşturulmuş habitat eğilimleri değerlendirilmiştir (Tablo 2).

Tablo 2. Türkiye'de bulunan bazı kekik türlerinin Habitat Eğilimleri

Tür Adı (*Thymus* türü)	**Endemik mi?**	**2025 Durumu**	**2050–2070 Öngörü (Kullanım sabitken)**
Thymus praecox	Evet	Yaygın dağ step habitatı	Azalma (İrtifa kayması, habitat daralması)
Thymus baseri	Evet (CR)	Çok dar alan, <250 birey	Daha da kritik (küçük popülasyon riski artar) (Öztürk ve ark., 2021)
Birçok *Thymus* türü (~42 sp, 47 takson)	Yaklaşık %50 endemik (20 endemik)	Geniş taksonomik çeşitlilik, birçok tür korunuyor	Toplam tür sayısı değişmez**,** ancak yerel popülasyon yoğunluğu ve dağılım azalır
Thymus aznavourii	Evet (Endangered→DD)	Riskli; Bilgi eksikliği	Belirsiz, belki kaybolma riski (takip gerek) Stoyanov ve Marinov (2021)

Kekik bitkilerinin kullanım alanının geniş olmasının yanı sıra kuraklığa karşı dayanıklı olması peyzaj tasarım çalışmalarında da tercih edilen bitkiler arasında yer almaktadır. Son zamanlarda artan sıcaklık azalan yağış oranları, parçalanan habitat alanları, yangınlar, kekik toplamaları, Fenolojik değişimler (çiçeklenme, tohumlanma zamanlaması), Ekstrem olayların artışı (kuraklık, sıcak hava dalgaları, don olayları), Yeni hastalık ve zararlıların yayılması gibi nedenlerle kekikler sürekli tehdit altında kalmaktadır.

Kekiklerin, Türkiye bölgelerinde risk değerlendirmesi yapıldığında, Akdeniz Bölgesi (kuraklık artışı, sıcak hava dalgaları), İç Anadolu (daha kurak yazlar, ilkbahar yağışlarının azalması), Doğu Karadeniz (bazı türler için yeni habitat alanı oluşturma potansiyeli) nedenleri ile kekiklerin (*Thymus vulgaris* (kekik), *Origanum onites* (İzmir kekiği)) yaşam alanını sınırlandırmaktadır.

Kekik türlerinin sürdürülebilirliğini etkileyen faktörlerin başında, Tarım yapılmayan, vahşi ortamdan toplama yöntemidir. Aşırı toplama ve yasa dışı ticaret nedeniyle birçok türde yok olma riski yaratmaktadır**.** Bunun için sağlamak için WHO ve IUCN gibi kurumlar, yabancı türlerin sürdürülebilir biçimde hasat yapılması için sertifikasyon sistemleri (örneğin FairWild Standard) geliştirmiştir

Kekiklerin bugünkü durumları irdelenip maruz kaldığı tehditler değerlendirildiğinde gelecek zamanlarda meydana gelebilecek değişimler şu şekilde özetlenebilir (Tablo 3):

Tablo 3. Kekik türlerinin kullanımı ve üretimi

Başlık	**2025 Durumu**	**2050–2070 Öngörüsü (aynı kullanım eğilimi varsayımıyla)**	**Gerekçe / Not**
Thymus tür sayısı (Türkiye)	Yaklaşık 39–42 tür / 47 takson; ~20 endemik	Tür sayısı nominalde benzer, ancak uygun habitat alanlarında daralma **ve** endemik popülasyonlar için risk artışı	İklim çalışmaları 2050 ve 2070'te *Thymus* için uygun alanların küçüldüğünü gösteriyor
Thymus dağılımı / habitat	Yüksek dağ/step mozaikleri; parça parça endemizm	Alt irtifalarda çekilme**,** yüksek irtifalara kayma**,** bazı lokal popülasyonlarda azalma	İklim değişikliği ve arazi kullanımı değişimi TAP'larda uygun alanı azaltıyor**.**

Başlık	**2025 Durumu**	**2050–2070 Öngörüsü (aynı kullanım eğilimi varsayımıyla)**	**Gerekçe / Not**
Origanum üretimi (İzmir kekiği ağırlıklı)	Denizli merkezli, tarla üretimi baskın; 2023'te 26.983 ton	Genel üretim hacmi yatay/ılımlı artış**;** fakat fiyat dalgalanması ve iklim/stres olaylarına duyarlı	Kültür üretimi pazar talebiyle sürer; 2024'te don/iklim ve fiyat dalgalanmaları etkisi raporlandı (Anonim, 2024).
Doğadan toplama baskısı	2000'lerden beri azalan rol (kültüre geçiş)	Benzer düşük düzeyde kalır; denetim/kota sürerse koruma lehine	Politikalar/denetim ve tedarik zinciri projeleri sürdürülebilirliği artırıyor (Anonim, 2024a).
İhracat ve pazar	Türkiye dünya pazarında lider; 2023'te yaklaşık 16.966 ton ihracat haberi	Talep güçlü kalır**;** kalite/rezidü standartları belirleyici	Pazar haberleri ve sürdürülebilir tedarik raporları talebin sürdüğünü gösteriyor (Anonim,2023).
Koruma riski (Thymus endemikleri)	Bazı türler "nadir/tehdit altında" kategorilerde	Risk artar (özellikle dar yayılışlı endemikler için)	Türkiye özelinde eski IUCN listeleri bile nadir/tehdit sinyali veriyordu; iklim etkisi bu riski büyütür. (Anonim, 2025a)

Thymus **sp. (dağ kekiği) tür zenginliği:** Türkiye'de yaklaşık 47 takson bulunmakta yaklaşık olarak %20'si endemik**.** (Anonim, 2025a).

Origanum **sp. (İzmir kekiği dâhil) tür zenginliği ve ticaret:** Türkiye'de 25–30 çeşit *Origanum* türü bulunur; *O. onites* (İzmir kekiği) ticari türdür ve üretim ağırlıkla Denizli'de tarla yetiştiriciliği ile yapılır (Anonim, 2024a).

Üretim/İhracat (2023–2024 civarı): Denizli'de 19.714 ha alanda 26.983 ton kekik üretimi; Türkiye, dünya pazarının büyük kısmını karşılıyor (Anonim, 2024a).

Toplama vs. kültür: 2000'lerden itibaren doğadan toplama hızla azaldı**,** kültür alanları baskın hâle geldi (Denizli'de yaklaşık olarak 85.000ha civarı ekili alan) (Anonim, 2024a).
Literatürlere bakıldığında, 2025 yılında**,** yaklaşık 17–28 bin arasında TAB türü kullanımda veya kayıtlı durumda. 2050–2070 yıllarında ise tür sayısı konusunda dolaylı veriler var piyasa büyüklüğü artışı, habitat kaybı, iklim değişikliği nedeniyle türler risk altındadır. Habitatın parçalı yapısı, dağlık alanların ısınması ve insan etkisi**,** pek çok türün yerel dağılımının daralmasına yol açacaktır.
Önlem olarak şunlar yapılabilir; Tarımsal *Origanum* sp. üretimi**:** Kültür üretimi hakim kaldığından toplam arzın korunması muhtemel; ancak ekstrem hava olayları, don ve fiyat değişkenliği üretim alanını ve çiftçi tercihini etkileyebilir
Türkiye'de başlıca *Thymus* sp. türlerinin sürekliliğini sağlamak amacıyla;

Tohum-anaç hatları & ex situ koleksiyonlar: Dar yayılışlı *Thymus* taksonlarında ex situ (tohum bankası, fidanlık) ve yerinde mikro-rezerv uygulamaları.

Kültür üretiminde iklim uyumu: Denizli ve çevresinde don–kuraklık risk haritası**,** çeşit/klon seçimi**,** toprak-su yönetimi ve kalıntı/PA izlemenin yaygınlaştırılması sağlanabilir.

Türkiye'de Isparta ve Malatya illerinde yapılan uygulamalar ile toplumun bilinçlenmesi, istihdam alanlarının oluşturulması ve sürdürülebilir çalışmalar gerçekleştirilmiş.
Isparta'da FAO ve Tarım Bakanlığı iş birliğiyle yürütülen "Value Chain" çalışması, gül ve lavanta gibi MAP ürünlerinde kırsalda kadın üreticilerin kooperatifleşmesini, ekolojik-sosyal ve ekonomik entegrasyonu sağlamayı hedeflenmiştir.
Öneri: Benzer "Değer Zinciri + Kadın Kooperatifleri" modelleri diğer bölgelerde (ör., kekik, adaçayı üretimi) hayata geçirilerek kırsal kalkınmaya, kadın istihdamına ve sürdürülebilir üretime katkı sağlanabilir.

Malatya'da yapılan bir çalışma, kent peyzajında 189 tıbbi/aromatik bitki türünün uygulanabilir olduğunu belirlenmiş, bu türlerin kent estetiği ve canlı kültürel miras olarak kullanımı önerilmiştir. **Öneri:** Belediyeler, şehir planlarında **"TAB Kent Bahçeleri"** ve yeşil alan projeleri geliştirerek hem biyolojik çeşitliliği destekleyebilir hem de toplumun bilinçlenmesine katkı sağlayabilir. Bu alanlarda yerel türlerin kullanımı sağlanmıştır.

Sonuç

Estetik ve görsel olan bitkiler peyzaj tasarım çalışmalarında kullanıma uygun olan bitkilerdir. Son zamanlarda artan sıcaklıklar ve kuraklık etkisi bitki türlerini sınırlandırmaktadır. Kekik bitkisinin görsel etkisi, sıcaklık ve kuraklığa karşı dayanıklılığı nedeni ile tasarım çalışmalarında çok yönlü kullanım olanağı sağlamaktadır. Değişik amaçlarla kullanımı olan kekik türlerinin aynı zamanda devamlılığının sağlanması için bir takım önlemlerin alınması gerekmektedir. Bunlar; bitkinin Ex-situ koruma (tohum bankaları, botanik bahçeler), ekolojik restorasyon ve yerel halkın katılımını (ekoturizm, aromatik bitki kooperatifleri) sağlamaktır.
Türkiye TARIM ve SANAYİ bakanlıkları, MAP üretiminde "Sürdürülebilirlik Rehberi" hazırlayıp çiftçilere ve işletmelere eğitimler düzenlemeli; atık valorizasyonu ve yeşil teknolojiler (örneğin biyogazla kurutma/ısıtma) teşvik edilmelidir.

Kaynaklar

Anonim, (2021). Tarım Ve Orman Bakanlığı. 2024 Organik Bitkisel Üretim Verileri. Tarım ve Orman Bakanlığı.(www.tarimorman.gov.tr). (Alıntı Tarihi. 13.08.2025)

Anonim, (2024). denizliyeniolay.com

Anonim, (2023). turkishagrinews.comIDH - the Sustainable Trade Initiative

Anonim, (2024a). denizli.tarimorman.gov.tr+1

Anonim, (2025). journals.brandonu.ca.

Anonim, (2025a). pmc.ncbi.nlm.nih.gov

Alipour, M., Haghighi, M., Rahimmalek, M., Reichelt, M., Martinelli, L., Groten, K. Mithöfer, A. (2025) Integrated metabolomics, transcriptomic, and phytohormonal analyses to study the effects of water stress and foliar abscisic acid application in Thymus species using LC-MS/MS. *Front. Plant Sci.* 16:1557446. doi: 10.3389/fpls.2025.1557446

Bayram, E., et al. (2010). Medical and aromatic plants in Turkey. *Acta Horticulturae*, 860, 23–32.

Ekor, M. (2014). The growing use of herbal medicines: issues relating to adverse reactions and challenges in monitoring safety. *Frontiers in Pharmacology*, 4, 177.

Güner, A., et al. (2012). Türkiye Bitkileri Listesi (Damarlı Bitkiler). *Nezahat Gökyiğit Botanik Bahçesi ve Flora Araştırmaları Derneği.*

Hosseini N, Ghorbanpour M, Mostafavi H. (2024).The influence of climate change on the future distribution of two Thymus species in Iran: MaxEnt model-based prediction. *BMC Plant Biol.* 2024 Apr 11;24(1):269. doi: 10.1186/s12870-024-04965-1. PMID: 38605338; PMCID: PMC11007882.

IPBES (2019). Global assessment report on biodiversity and ecosystem services.

Öztürk, D., Yaylaci, O. K., Koyuncu, O., Sezer, O., Ozgisi, K., & Ocak, A. (2021). A new species of Thymus (Lamiaceae) from central Anatolia (Turkey). *Pakistan Journal of Botany,* 54(2). https://doi.org/10.30848/pjb2022-2(7)

Power, A. G. (2010). Ecosystem services and agriculture: tradeoffs and synergies. *Philosophical Transactions of the Royal Society B*, 365(1554), 2959–2971.

Rates, S. M. K. (2001). Plants as source of drugs. *Toxicon*, 39(5), 603–613.

Stoyanov, S. Marinov, Y. (2021). *Thymus aznavourii* (Lamiaceae): first records for Bulgarian and Greek flora. *Proceedings of the Bulgarian Academy of Sciences* 74(3):352-362. DOI:10.7546/CRABS.2021.03.06

WHO (2013). *WHO* traditional medicine strategy*:* 2014–2023. World Health Organization.

Zamani, S., Fathi, M., , Ebadi, M.T., Math, A. (2025). Global trade of medicinal and aromatic plants. A review. *Journal of Agriculture and Food Research.* Volume 21, June 2025, 101910

Ağaçların Mitolojisi: Kültürlerde Kutsal ve Sihirli Ağaçlar

Gülden Sandal Erzurumlu

Niğde Ömer Halisdemir Üniversitesi, Mimarlık Fakültesi, Peyzaj Mimarlığı Bölümü, Niğde
E mail:gpeyzaj@gmail.com

Özet
Ağaçlarda efsane" ifadesi, belirli ağaç türleriyle ilgili olarak kuşaktan kuşağa aktarılan mitolojik, folklorik veya kültürel hikâyeler, inanışlar ve semboller anlamına gelir. Yani yalnızca fiziksel özellikleriyle değil, insanlar için taşıdığı anlam, güç, gizem ve kutsallık ile ilgilidir.

Bu çalışma, kültür ve bilişsel önyargılara derinden kök salmış Türk kültürüne ait seçilmiş bazı ağaçların batıl inançların bilimsel geçerliliğini, bilimsel ilerlemelere rağmen kanıt ve akıl yürütmeyle uyumları açısından incelenmektedir.

Buna karşılık, gece süpürmekten kaçınmak veya avuç içinin kaşınmasını parayla ilişkilendirmek gibi inançların bilimsel temelden yoksun olduğu; çoğunlukla anekdotsal kanıtlardan veya kültürel sembolizmden kaynaklandığı görülmüştür. Ağaçlar konusunda da kültürel inançlardan kaynaklandığı söylenebilir.Çalışma, bazı batıl inançların rasyonel temellere sahip olabileceğini, ancak bunların kalıcılığının esasen kültürel anlatılar ve psikolojik ihtiyaçlardan beslendiğini ortaya koymaktadır. Sonuç olarak, geleneksel inançların değerlendirilmesinde eleştirel düşünme, bilimsel okuryazarlık ve kültürel farkındalığın gerekliliğine dikkat çekilmektedir.

Bu çalışma, ağaçların mitolojik ve kültürel temellerini analiz etmeyi amaçlamakta ve farklı inanışlarda ağaç türlerinin sembolik anlamların çeşitliliğini karşılaştırmalı olarak ele almaktadır.
Anahtar Kelimeler: *Ağaç Kültü, Mitoloji, Batıl İnanç, Türk Kültürü, Niğde*

The Mythology of Trees: Sacred and Magical Trees in Cultures

Abstract

The mythology of trees embodies a wide range of mythological, folkloric, and cultural narratives transmitted across generations, emphasizing not only their physical features but also the meanings, powers, mysteries, and sacredness attributed to them.

This study investigates selected tree species within Turkish culture, which are deeply rooted in traditions and cognitive biases, in order to examine the scientific validity of related superstitions and their consistency with reasoning and evidence despite modern scientific progress.

While some beliefs such as avoiding sweeping at night or linking itchy palms to Money lack scientific foundation and are mostly derived from anecdotal evidence or symbolic cultural associations, similar patterns can also be observed in tree-related beliefs. The findings suggest that certain superstitions may hold rational elements; however, their persistence is primarily sustained by cultural narratives and psychological needs.

The study highlights the necessity of critical thinking, scientific literacy, and cultural awareness in the evaluation of traditional beliefs. Ultimately, it provides a comparative perspective on the symbolic diversity of tree species in different cultural and religious contexts, contributing to a broader understanding of the mythological and cultural foundations of trees.

Keywords: Tree Cult, Mythology, Superstition, Turkish Culture

Giriş
Ağaçlarla ilgili inançlar, insan kültürünün yaygın bir unsuru olarak tarih boyunca varlığını sürdürmüş, açıklanamayan olaylara açıklamalar sunmuş ve belirsiz bir dünyada kontrol duygusu sağlamıştır (Vyse, 2023). Kişisel ritüellerden geniş çaplı kültürel uygulamalara kadar uzanan bu inançlar, çoğu zaman geleneksel bilimsel anlayışa aykırı olsa da insan davranışlarını ve karar alma süreçlerini etkilemeye devam etmektedir.

İlk insan atalarımızın yeryüzünde ne zaman evrimleştiği konusunda göreceli bir belirsizlik bulunmaktadır. Ancak o zamana kadar gezegenimizde sayısız bitki ve ağaç çeşidi gelişmektedir. Gövdesi dallara, ince dallara ve yapraklara ayrılan bir ağacın yapısı, evren ile arasındaki ilişkiyi karakterize eden felsefi kavramın fiziksel bir yansımasından oluşmaktadır. Ağacın gizli kökleri, gizli bir köken veya kaynaktan doğan birlik metaforunu daha da ileri götürmektedir. İnsanın kendisinden bile daha eski olan ağaçlar, neredeyse tüm kültürlerde teselli, güç, bereket ve ölümsüzlüğün sembolleri olarak kullanımı inançların ayrılmaz bir parçası olmuştur.

Tek bir ağaç genellikle köklerinden dal uçlarına kadar bir yaşam evrenine ev sahipliği yapar. Yine de kendileri ayrı, sessiz nöbetçiler izlenimi verebilirler. Bilim insanları ağaçların görebildiğini, öğrenebildiğini, iletişim kurabildiğini ve sosyal davranışlar sergileyebildiğini, hasarlı veya ölmekte olan komşularını beslemek ve korumak için ittifaklar kurabildiğini ancak şimdi keşfetmeye başlamıştır (Wohlleben, 2016). Eğer bilinç, duyarlılığın niteliği, çevreyi algılama ve ona tepki verme yeteneği olarak tanımlanırsa, o zaman bu muhteşem varlıklar kesinlikle bu tanıma uymaktadır. Eğer bilinç düzeyi bilgiyi işleme, ayırt etme, bütünleştirme ve iletme yeteneğine bağlıysa, o zaman bilincin yalnızca insanlığa özgü olmadığı açıkça belirtilebilir (Anonim, Tarihsiz). Ve eğer yaşın ve deneyimin bilgeliğe katkıda bulunabileceğine inanıyorsak, yüzlerce ve hatta binlerce yıl süren yaşamları olan ağaçların, eğer dinlemeyi öğrenebilseydik, yaşam hakkında iletecek çok şeyi olabilecektir. Ağaçlar, insanoğlundan daha eski çağlara dayanan, teselli, güç, bereket ve ölümsüzlük sembolleri olarak hemen hemen bütün kültürlerde mitlerin ve folklorun ayrılmaz bir parçası olmuştur. Ağaçların kış uykusuna yatmak için yapraklarını döktüğü enlemlerde, mevsimsel olmayan bir sıcak dönem ile baharın kesin gelişi arasındaki farkı nasıl ayırt ediyorlar? Meyve ağaçları üzerinde çalışan bilim insanları, bu ağaçların 'uyanma' sürecine başlamadan önce belirli bir süre arka arkaya sıcak günlerin gelmesini beklediklerini belgelemişlerdir. Örneğin kayın ağaçları ancak günde en az on üç saat gün ışığı olduğunda yeni yapraklar çıkarmaya başlıyor. Bu şaşırtıcı kanıt, ağaçların ışığın varlığını "görebildiğini" veya kaydedebildiğini ve gün uzunluklarını karşılaştırmak ve sıcak günleri saymak için bir tür hafıza kullandığını gösterdiğini bildirilmektedir (Wohlleben, 2016).

Ağaçlar Arasında İletişim
Ağaçlar birbirleriyle koku yoluyla oldukça net bir şekilde "konuşur" ve tehlikeye karşı uyarır. Afrika Savanası'ndaki bilim insanları, zürafaların beslendiği Akasya ağaçlarının, komşu ağaçları uyarmak için etilen gazı salgılarken, acı ve etkili bir caydırıcı olarak yapraklarına toksin pompalamaya başladığını keşfetmişlerdir. Önceden uyarılan ağaçlar da yapraklarına toksin pompalamaya başlayarak rüzgârın estiği yöndeki diğer ağaçları uyarıyor. Farklı saldırgan böceklerin tükürüklerini tanıyabilen ve zararlı böcekleri yemeleri için belirli avcıları "çağırmak" üzere bileşikler üreterek onlarla savaşan ağaçlar bulunmaktadır.

İletişim yeraltında da gerçekleşebilir. Bir ağacın kökleri, tacının çok ötesine uzanabilir, komşularının kökleriyle kesişebilir ve çaprazlama kesişebilir. 1990 yılında Suzanne Simard, mantarların kendilerini kök uçlarına bağlayarak ince filamentler ya da hifler salgıladıklarını, bu filamentlerin topraktan geçerek kilometrelerce uzunluktaki orman kök sistemlerini ördüğünü ve böcekler, kuraklık ya da diğer tehlikeler hakkında bilgi alışverişinde bulunmak üzere bir ağaçtan diğerine sinyal taşıyabilen bir ağ oluşturduğunu keşfetmiştir. Yüzyıllar boyunca tek bir mantar bütün bir ormanı ağ gibi sarabilir, bu da Nature dergisinin bu fenomeni 'Wood Wide Web' olarak adlandırmasına neden olmuştur (Anonim, Tarihsiz).

Ağaçların Işığı Araması
Uygun olmayan koşullardaki ağaçlar mevcut ışıktan en iyi şekilde yararlanmak için uyum sağlar. Bol ışık alan ağaçlar yanlara doğru dalarak geniş bir gölgelik oluşturur. Ancak aynı tür, komşularına yakın olduğunda, daha yükseklerde bol ışığa ulaşmak için daha uzun, daha ince bir gövde geliştirerek düz yukarı doğru büyümektedir. Bazı türler ışığa doğru uzanırken zaman içinde kendilerini eğip bükerek uyum sağlar.

Mevcut güneş ışığı ile yapraklardaki klorofil, bir ağacın fotosentez yapmasını sağlar, karbondioksit ve su varlığında güneş ışığını yakalayarak gerekli şekerleri üretirken oksijeni havaya geri salar. Güneş ışığı ve su azaldıkça, yaprak döken ağaçlar klorofili parçalayarak ve yaprak sapının dala tutunmasını gevşeterek kış boyunca enerji tasarrufu sağlar. Yeşil klorofil soldukça diğer göz kamaştırıcı pigmentler görünür hale gelir: ksantofilin parlak sarısı, karotenoidlerin yanan turuncusu ve klorofilin yeşil pelerini altında görünmez olan antosiyaninlerin göz kamaştırıcı kırmızıları ve morları bulunmaktadır (Anonim, 2021).

Bir ormandaki her ağaç benzersiz bir yerde yetişir ve toprak, su ve besin maddeleri gibi yetişme koşulları küçük mesafelerde bile büyük farklılıklar gösterebilir. Bu durum, her bir ağacın fotosentez oranıyla ölçülen gücü ve sağlığında farklılıklar yaratmalıdır. Ancak Aachen Çevre Araştırmaları Enstitüsü'ndeki öğrenciler, bozulmamış bir Kayın ormanında ağaçların köklerinde iç içe geçmiş mantar ağı aracılığıyla besinleri paylaştığını, böylece fotosentez oranının tüm ağaçlar için aynı olduğunu keşfetti. Bu, zengin yetişme koşullarındaki "daha güçlü" ağaçların, daha yoksun olanlara şeker ve su vererek hayatta kalmalarını sağladığı anlamına gelmektedir.

Aslında çok daha uzun yaşam süreleri, ağaçların zamanı nispeten kısa görüşlü insan görüşünden farklı bir şekilde deneyimlemelerine izin veriyor gibi görünmektedir. Ağaç örtüsündeki boşluklardan sıcak güneş nemli zemini kurutabilir, dönen rüzgârlar besin açısından zengin humus oluşumunu bozabilir ve çalkantılı fırtınalar sızarak yıkıma neden olabilir. Ağaç gövdelerini tehlikeli bir şekilde bükülme noktalarının ötesine savurabilen kasırga şiddetindeki rüzgârlarda, her ağaç komşularını korumak için ayrılmaz bir rol oynar. Gövdelerin ve dalların benzersiz özelliklerindeki küçük farklılıklar, ağaçların hafifçe farklı hızlarda sallanmasına, birbirlerinin taçlarına hafifçe çarparak genel salınımı ve eğim açısını azaltmasına izin verir. Ancak bu sadece ağaçlar birbirine çok yakın konumlandırıldığında mümkün olmaktadır. Böylece, topluluğun dezavantajlı veya hastalıklı üyeleri, türlerine bakılmaksızın, daha zengin komşulardan gelen temel besinlerle korunur ve desteklenir, tüm ormanın gücüne katkıda bulunmaktadır (Wohlleben, 2016).

Ağaçlar, kökenler, beslenme, Tanrı ile temas, cennete yükselme, sağlık ve dileklerin yerine getirilmesiyle ilgili olanlar da dahil olmak üzere birçok dini ve felsefi gelenekte aracı bir rol oynamaktadır. Bu yüzden birçok kültür ağaçlara kutsal ikonlar olarak saygı duyar.

Örnek olarak, Titreyen Dev olarak da bilinen (*Populus tremuloides*), Utah'ta 106 dönümlük bir alana yayılmış, genetik olarak birbirinin aynısı 47.000 ağaçtan oluşuyor. Titrek kavaklar tohum yerine köklerinden sürgünler çıkararak ürerler. Bu sürgünler toprakta yükselir ve büyüyerek tamamen olgun ağaçlara dönüşür. Tek tek ağaçlardan oluşan bir orman gibi görünen bu yapı, aslında karmaşık bir yeraltı kök sistemiyle birbirine bağlı dev bir organizmadır. Her bir ağaç yaklaşık 130 yaşında olsa da, Titrek kavakların 80.000 yaşında olduğu tahmin ediliyor (Rals, 2019).

Bilim adamlarına göre hayat ağacı, evrimleşen yaratıklar tarafından paylaşılan neslin bir diyagramını andırır ve dört Akhshij (doğanın dört ana unsuru) ile ilgili bir sembol olarak kabul edilir; yapraklar rüzgarla, kökler toprakla, saplardaki akan özsu suyla ve odun ateşle ilişkilendirilir. Bu dört unsur (yani su, rüzgâr, ateş ve toprak) atalarımızın dünyamızı yarattığına inandıkları dört ana maddedir.

Benzer şekilde, Hinduizm'de ağaçlar uzun zamandır kutsal ve hayat verici olarak kabul edilmektedir. Özellikle Banyan (*Ficus benghalensis*) ağacı, ölümsüzlüğün ve ilahi bilgeliğin sembolü olarak kabul edilir. Tanrıların ve bilgelerin meskeni olduğuna inanılır ve geniş kubbesi barınak ve koruma sağlamaktadır. Siddhartha Gautama'nın aydınlanmaya erişip Buda olduğu Bodhi (*Ficus religiosa*) ağacı, Hindu ve Budist geleneklerinde ruhsal uyanış ve şifanın bir diğer güçlü sembolüdür. Buda'nın yaptığı gibi ağaçların altında meditasyon yapma pratiği, bu geleneklerde ruhsal pratiğin önemli bir parçası olmaya devam etmektedir.

Antik Yunan'da ağaçlar şifalı özellikleri nedeniyle de saygı görmektedir. Örneğin zeytin ağacı, tanrıça Athena'ya adanmıştı ve barış, bilgelik ve refahı simgelemektedir. Ağaçtan elde edilen zeytinyağı, çeşitli tıbbi ve ritüel uygulamalarda kullanılmaktadır. Yunanlılar ayrıca, tanrı Apollon ile ilişkilendirilen defne ağacının iyileştirici gücüne inanmaktadır. Defne yaprakları, galipleri taçlandırmak için kullanılırdı ve koruma ve şifa getirdiğine inanılmaktadır.

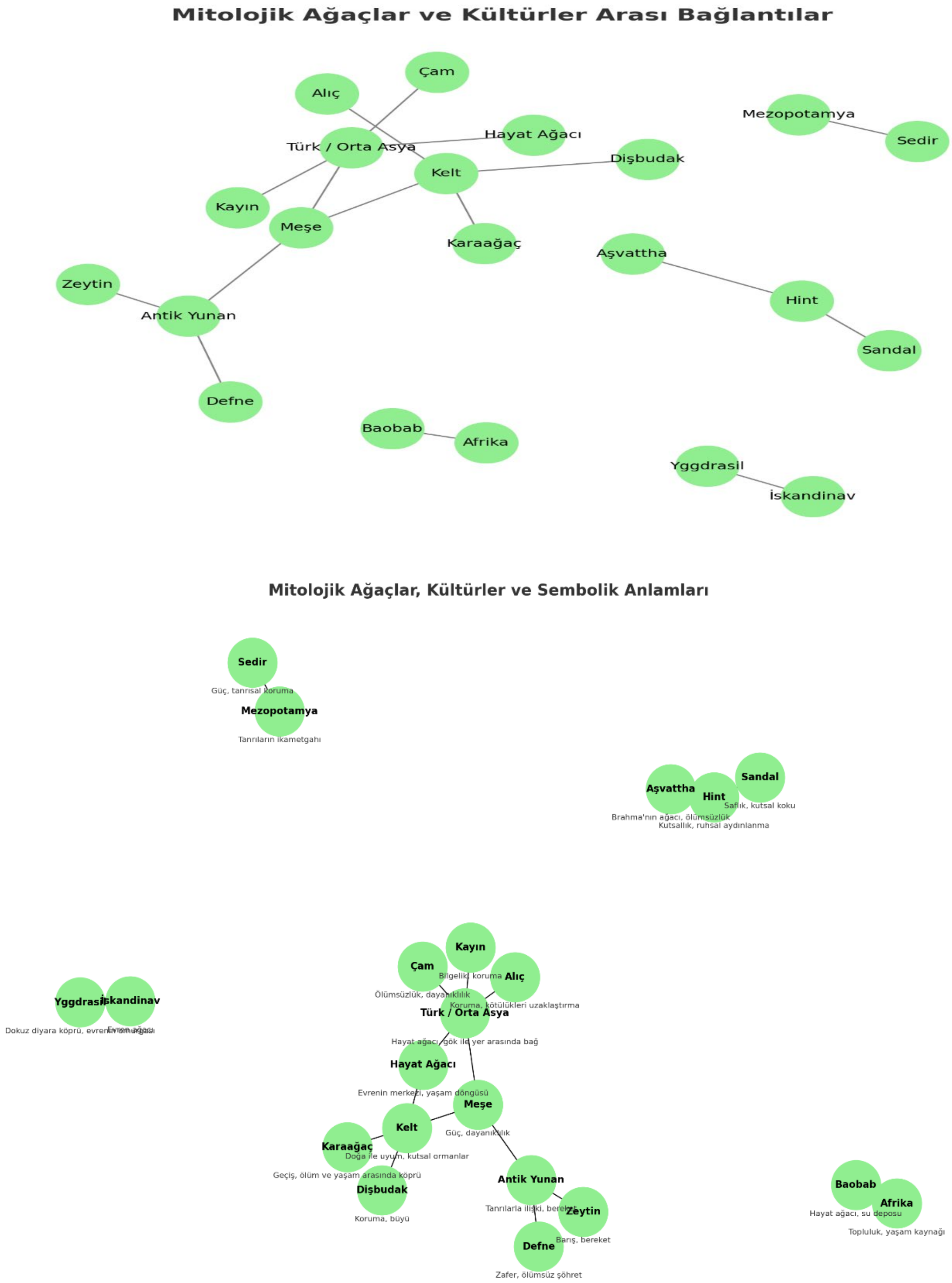
Yerli Amerikan geleneklerinde ağaçlar kutsal akrabalar olarak kabul edilir ve hayat veren ve iyileştirici özellikleri nedeniyle büyük saygı görmektedirler. Birçok kabilenin özel bir öneme sahip belirli ağaçları vardır ve çeşitli şifa ritüellerinde kullanılırlar. Örneğin sedir ağacı büyük saygı görür ve arınma törenlerinde ve şifa ritüellerinde kullanılır. Sedirin kabuğu, yaprakları ve odunu ilaç ve koruyucu muska yapımında kullanılmaktadır. Benzer şekilde, söğüt ağacı da tıbbi özellikleriyle bilinir ve kabuğu yüzyıllardır ağrı ve iltihabı hafifletmek için kullanılmıştır.

Afrika kültürleri de ağaçlara şifalı özellikleri nedeniyle büyük önem verir. Genellikle "hayat ağacı" olarak anılan baobab ağacı, birçok Afrika geleneğinde kutsal kabul edilmektedir. Meyvesi, yaprakları ve kabuğu, geleneksel tıpta ateş, ishal ve cilt rahatsızlıkları gibi çeşitli rahatsızlıkların tedavisinde kullanılır. Baobab ağacı aynı zamanda zorlu ortamlarda gelişme yeteneğini yansıtan güç, dayanıklılık ve uzun ömürlülüğün sembolü olarak da görülür.

Eski Mısırlılar, ağaçlara, özellikle de tanrıça Hathor ile ilişkilendirilen incir (*Ficus carica*) ağacına derin bir saygı duymaktadırlar. İncir ağacının öbür dünyaya açılan bir kapı ve ölenler için bir besin ve şifa kaynağı olduğuna inanılırdı. Mısırlılar, ağacın çeşitli kısımlarını tıbbi uygulamalarında kullanırlardı ve sütlü özsuyunun koruyucu ve iyileştirici özelliklere sahip olduğuna inanmaktadırlar (Sinha, 2024).

Mitolojik Ağaçlar ve Kültürler arasında bağlantılar:

Bir çok kültürde farklı ağaçlara farklı batıl inançlar bulunmaktadır. Bazı ağaçlar ise ortak olarak inançlar içerisinde yer almaktadır. Çam, Alıç, Kayın, Meşe vb ağaçlar genelde isimleri geçen ağalardandır. Türk ve Orta Asya kültüründe; alıç, çam, kayın, meşe ve hayat ağacı ile bağlantılı olduğu hakkında bilgiler paylaşılmaktadır (Şekil 1).



Şekil 1. Mitolojik Ağaçlar ve Kültürler arasında bağlantılar

Mitolojik ağaçlar ve kültürler arasında bağlantılar hakkında bilgiler aşağıda verilmektedir.

Tahtaya vurmak

Antik Keltler, tanrıların ve ruhların ağaçlarda yaşadığına inanır ve ağaca dokunmanın, koruma talep ettiğinizi ruhlara bildirebileceğini ya da tahtaya vurarak kötü ruhları korkutabileceğini düşünürlerdi.

Bazıları ise bunun, Hristiyanların İsa Mesih'in çarmıha gerildiği tahtaya dokunmanın koruma getireceğine inandıkları zamana dayandığını öne sürer. İngiliz folkloristi Steve Roud'a göre bu uygulama, 1800'lerde bir çocuk oyunundan gelmektedir; oyunda oyuncular bir şeyin tahtadan yapılmış bir parçasına dokunurlarsa güvende olurlardı. Ağaçlar insan kültürünün büyük bir parçasıdır ve her zaman öyle olmuştur. Bu yüzden onları batıl inançlarımıza dahil etmemiz şaşırtıcı değildir.

Diş Budak (*Fraxinus* sp.)
Son zamanlarda İskandinav mitolojisi irdelendiğinde, Yggdrasil veya yaşam ağacı, dokuz dünyanın etrafında var olduğu düşünülen devasa bir ağaçtır. Bu ağacın dalları göklere uzanır; kökleri ise yer altındaki kuyulara ve pınarlara uzanmaktadır. Geçmişte Britanya Adaları'nda insanlar, yeni doğan bebeklere biraz dişbudak özü vermenin onları iyileştireceğine veya güçlü tutacağına inanmışlardır. Bazıları da çocuğu dişbudak ağacının dallarının arasından geçirmekle korunacağına inanırdı.
Huş Ağacı (*Betula sp.*)
Bireysel olarak bu ağaçlar yaklaşık 150 yıl yaşar, ancak sık koloniler hâlinde büyümektedirler.
Betula verrucosa, B. pendula ve *B. pubescens* türleri, Finlandiya'da yaygın olarak bulunur.
Kültürel önemi: Bu ağaçlar, Finlandiya'nın altı ulusal doğa sembolünden biri olarak kabul edilir ve ülkedeki folklorda önemli bir yer tutar.
Folklorik rolü: Finlandiya halk hikâyelerinde ve geleneklerinde kayın ağaçları, saflık, yenilenme ve koruma ile ilişkilendirilir. Baharın gelişi genellikle kayın dallarının kullanımıyla kutlanmaktadır.

Kayın ağacı Anadolu'da bazı yerlerde de kutsal ağaç olarak nitelendirilmiş ve çeşitli nedenlerle ziyaret edilmiştir. Tokat'ın Niksar ilçesine bağlı Çolaklar Mezrası'nda bulunan ulu kayın ağacı halk tarafından kutsiyetine inanılan bir ağaçtır. Dilek sahipleri dua ettikten sonra üzerlerindeki giysilerden bir parça yırtarak ağaca nezir olarak bağlarlar (Sevindik ve Kara, 2023).

İngiltere'de kayından yapılan besom süpürgeler, kötü büyü ve kötü enerjileri temizlemek için kullanılmaktadır. Günümüzde bazı bahçıvanlar hâlâ bahçelerini kayın besom ile süpürerek kötü enerjiden arındırmayı dener. Kısaca kayın ağacı folklorda ve büyüsel inanışlarda koruma, yenilenme, rehberlik ve kötü enerjilerden arınma ile özdeşleştirilmiş kutsal bir ağaçtır.
Peyzajda Kullanımı: Bahçe ve park tasarımlarında dekoratif odak noktası olarak tercih edilir.

Folklorik ve Büyüsel Bağlam
Kayın ağaçları aynı kutsallık, koruma ve yenilenme sembollerini paylaşır. Özellikle su kenarlarında yetişen river birch, arıtma ve temizleme anlamında mistik özellikler taşır; su ve ağacın birleşimi, ritüellerde kötü enerjileri uzaklaştırma ile ilişkilendirilmiştir.

Sedir Ağacı (*Cedrus sp.*)
Peyzajda Kullanımı: Büyük boylu, uzun ömürlü ve dekoratif ağaçlar; genellikle parklar ve geniş bahçelerde gölge ve estetik sağlar. Ağaçtan yapılan malzemeler (barınak, kano, giysi) hem fiziksel hayatta kalma hem de kültürel ritüeller için hayati öneme sahiptir.
Kabileler, seremoni ve ruhsal yenilenme için redcedar ağaçlarının diplerinde bir araya gelirdi.
Totem direkleri çoğunlukla bu ağaçlardan yapılırdı; hem kültürel hem de dini simge olarak işlev görürdü. Uzun ömürlü ve devasa boyutlarıyla (yüzlerce feet boy ve 1.500 yıl yaşam), topluluklar için sürekli bir koruma ve süreklilik sembolü olmuştur.

Fındık Ağacı (*Coryllus* sp.)
Kehanet ve ilham büyüleri: Fındık yaprakları veya kabuğu tütsü yapılarak sezgilerin güçlendirileceğine inanılırdı.
Koruma amuletleri: Fındık dalından yapılmış küçük haçlar, evleri kötü ruhlardan korumak için kapılara asılırdı.
Bereket ritüelleri: Hasat öncesi fındık kabukları tarlalara bırakılarak verim artırmaya çalışılırdı.

Defne Ağacı *(Laurus nobilis)*
Koruyucu ve büyüsel kullanım:
Eski Yunan ve Roma'da defne dalları koruyucu bir güç olarak görülür, kötü ruhlardan ve felaketlerden korunmak için kullanılırdı. Evlerin girişine veya törenlerde dallar yerleştirilirdi.
Başarı ve ilham: Şairler, sanatçılar veya kahramanlar, laurel tacı takarak ilham ve şansı artırmayı amaçlardı. Bazı kültürlerde defne dallarının evde tutulması sakinlik, refah ve korunma getireceğine inanılırdı.

Ihlamur Ağacı (*Tilia spp.*)
Ihlamur, sevgi, sadakat ve misafirperverlik ile ilişkilendirilir.
Avrupa halk inançlarında koruma, sakinleştirici ve dostluk sembolü olarak görülür. Linden altında oturmak veya dallarını kullanmak sevgi, uyum ve huzur getirebilir.

Avrupa halk inançlarında, ağaçların etrafında yapılan ritüeller, koruma ve dostluk sembolü olarak görülür. Çiçeklerinin yoğun tatlı kokusu, insanları etkiler ve sevinç, huzur ve aşk duygularını tetiklediğine inanılır. Arılarla birlikte açtığında, ağaç doğayla ve kozmik enerjilerle bağlantı kurma hissi verir. Amerikan ıhlamuru (*T. americana*) gibi türler, bahçelerde hem estetik hem de manevi fayda sağlayan seçenekler olarak değerlendirilir.

Dut ağacı (*Morus* spp.)
Kültüre göre dut ağacı hem uğurlu hem uğursuz kabul edilir. Bazı bölgelerde kötü şans veya hüzünle ilişkilendirilir, bazen de koruyucu ve verimli bir ağaç olarak görülür.
Bazı halk inanışlarında kötü ruhları uzaklaştırmak için dut ağacının dalları veya meyveleri kullanılır. Meyve veya yapraklarının koruyucu tılsımlar yapmakta kullanıldığı kaydedilmiştir.
Dut ağacı hem yaratıcı, bereketli bir sembol hem de hüzün veya trajedi ile ilişkilendirilen bir bitkidir. Farklı kültürlerde anlamı, coğrafya ve mitolojik bağlam ile değişiklik gösterir.

Meşe Ağacı (*Quercus* sp.)
70 m'ye kadar boylanabilir, sonbaharda kırmızı, turuncu ve sarı yapraklarla görsel şölen sunar.

Rose (*Rosa* spp.) – Gül
Gül, uzun süredir sevgi ve aşkın simgesi olarak görülüyor. Beyaz güller kırmızıya dönüşerek tutkulu aşkı temsil eder. Beyaz güller genellikle **masumiyet, anma ve koruma** ile ilişkilendirilir.
R. laevigata, çeşitli toprak koşullarına dayanıklı, yarı gölgeyi tercih eden ve kuraklığa dayanabilen bir türdür.Dayanıklı ve verimli bir bitkidir; bahçelerde yaygın olarak yetiştirilebilir.

Üvez Ağacı (*Sorbus sp.)*
Kötü Ruhlardan ve Cadılardan Koruma; Kapı üstlerine dallar asmak, aynı korumayı sağlardı. Almanlar, rowan dalını yanında taşımayı koruyucu bir uygulama olarak görürdü. Bu inanış, Almanya'dan Pennsylvania'ya göç edenler tarafından çocukların paltolarına Üvez dalı takma biçiminde devam ettirilmiş. Ağacın parlak kırmızı meyvelerinin bol olması, sert ve uzun bir kışın geleceği anlamına gelir diye inanılırdı.

İncir Ağacı (***Ficus carica***)
Ev ve bahçe çevresine dikildiğinde kötü ruhları uzaklaştırdığına inanılır. Meyveleri ve yaprakları bereket, sağlık ve bolluk için tılsımlarda kullanılmıştır. Eşlerin evine incir ağacı dikmesi, evlilikte uyum ve sevgiyi artırdığına inanılır. Bazı kültürlerde, meditasyon ve bilgelik kazanmak için ağacın gölgesinde otururlurdu.

Ceviz ağacı (*Juglans spp*.)
Birçok kültürde hem mitolojik hem de folklorik öneme sahiptir. Evlerin önüne veya bahçeye ceviz ağacı dikmek kötü ruhları uzaklaştıracağına inanılırdı. Ceviz kabuğu veya yaprağı ile yapılan bazı ritüeller, geleceği görmeye veya rüyaları yorumlamaya yöneliktir.

Kavak Ağacı (*Populus* sp.)
Kavak yapraklarının uzun saplı ve rüzgarda sürekli titreyen yapısı, "konuşan ağaç" veya kehanet işareti olarak yorumlanırdı. Kavak altına oturan veya uyuyan kişinin, rüya yoluyla geleceğe dair mesajlar alacağına inanılırdı. Bazı Avrupa halklarında kavak kabuğu veya yaprakları, büyü ritüellerinde veya şifa amaçlı kullanılmaktaydı. Kavak ağaçları, ölüm ve öte dünya ile bağlantılı kabul edilirdi; bazı halk inanışlarında ruhların bu ağaçların etrafında dolaştığına inanılırdı.
Kavak ağaçları, özellikle "titreşen yaprakları" nedeniyle huzur ve sakinlik sembolü olarak kabul edilir. Peyzaj ve bahçelerde, estetik ve mitolojik özellikleri bir arada değerlendirilebilir.

Çınar Ağacı (*Platanus* sp.)
Köy meydanlarında veya evlerin yakınında çınar dikmek kötü ruhları uzaklaştırdığına inanılırdı. Çınar kabuğu ve yaprakları eski halk tıbbında çeşitli hastalıklar için kullanılırdı. Halk efsanelerinde köylerdeki en yaşlı çınarın altında kararlar alınır, adalet ve bilgelik sembolü olarak görülürdü. Günümüzde ceviz ağacı hâlâ bereket, sağlık ve uzun ömür sembolü olarak görülür. Bahçelerde veya peyzajlarda kullanımı hem estetik hem de geleneksel kültürel bağ açısından önem taşır (Tablo 1).
Tablo 1. Ağaçların Geleneksel Kültürel Bağları

Ağaç	**Mitolojik / Kültürel Bağlantılar**	**Folklorik / Büyüsel Kullanımlar**	**Sembolizm / Anlam**
Kavak *Populus spp.*)	Avrupa ve Kelt mitolojisinde ölüm ve öte	Yapraklarının titreşmesi kehanet işareti olarak kabul edilirdi; bazı bölgelerde şifa ve büyü ritüellerinde kullanılmıştır. Evin yakınlarına dikilerek kötü ruhları uzak tuttuğuna inanılır;	Hüzün, dönüşüm, ruhsal geçiş, korunma

Ağaç	Mitolojik / Kültürel Bağlantılar	Folklorik / Büyüsel Kullanımlar	Sembolizm / Anlam
	dünya ile bağlantılı; rüya ve vizyon sembolü	çocukların hastalıklardan korunması için dallarına dokundurulur.	
Ceviz (*Juglans regia*)	Antik Yunan'da bilgelik ve zeka sembolü; Roma ve Kelt mitolojisinde bereket ve güçle ilişkili	Fındık ve ceviz kabuğu ile fal bakma; bebeklerin korunması için ritüeller. Düğün ve doğum ritüellerinde kötü gözden korunmak için kullanılır; evin çevresine dikilen ceviz ağaçları nazarı önler.	Bilgelik, koruma, bereket, güç
Meşe (*Quercus spp.*)	Yunan mitolojisinde Zeus'un ağacı; İskandinav mitolojisinde Thor'un ağacı; Keltlerde kutsal ağaç	Tannins şifa amaçlı; mistletoe ile ritüeller; güç ve koruma için kullanılır	Güç, koruma, uzun ömür, tanrısal bağ
Ihlamur / (*Tilia spp.*)	Yunan, Norse ve Kelt mitolojisinde aşk, uyum ve topluluk sembolü	Ev ve köylerde kötü ruhları uzaklaştırma; aşk ve uyum ritüellerinde kullanılmış	Sevgi, uyum, koruma, topluluk

Dilek ve Ritüel Ağaçları
Bazı ağaçlar sadece mitolojik değil, halk inançlarında dilek, şifa veya nazar için kullanılır (Tablo 2):
İnsanlar dallara ip, kurdele veya bez bağlayarak dilek diler. Bazı kültürlerde doğum, evlilik veya hastalık gibi özel anlarda ağaçlar kutsal kabul edilir. Örnekler:
Rowan / Dağ Kızılağacı: Cadılardan korunma, kötü ruhları uzaklaştırma.
Ihlamur ve Meşe: Aşk ve barış dilemek için halk ritüellerinde kullanılır.
Ağaçlar hem fiziksel hem de sembolik olarak insan yaşamında merkezi bir yer tutmaktadır. Mitoloji ve folklor, ağaçları sadece doğa varlığı değil, ruhsal ve büyüsel güç kaynağı olarak ele almaktadır. Farklı kültürlerde ağaçların kullanımı, insanın doğayla kurduğu bağ ve ritüel anlayışını yansıtmaktadır.
Tablo 2. Halk İnançlarında Dilek Ağacı Örnekleri

Kültür / Bölge	Dilek Ağacı Örneği	Açıklama
Türkiye	*Fıstık çamı, kavak, ıhlamur gibi yerel ağaçlar*	İnsanlar dileklerini kurdeleye yazar, ağacın dallarına bağlar. Özellikle cami ve türbe yakınlarında görülür.
Japonya	*Ema ağaçları (tapınaklarda)*	Küçük tahta levhalara dilek yazılır ve tapınaklardaki ağaca asılır.
Çin	*Şeftali ve kiraz ağaçları*	Yeni yıl ve bahar festivalinde dilekler asılır, şans ve bereket getirdiğine inanılır.
İngiltere / İskoçya	*Wishing Trees*	Dilekler renkli kurdeleler veya kumaş parçalarıyla ağaç dallarına bağlanır; halk inançlarına göre dilek gerçekleşir.

Tanrılar, kahramanlar veya doğaüstü varlıklarla ilişkili anlatılar (ör. Yunan mitolojisinde meşe ağacı Zeus ile ilişkilendirilir). Halkın kuşaktan kuşağa aktardığı inanışlar, ritüeller veya gelenekler (ör. çınar ağacının köyleri kötü ruhlardan koruduğuna inanılması). Sabır, güç, bilgelik, aşk gibi soyut değerlerin ağaçlarla temsil edilmesi. Kısaca, "ağaçlarda efsane" ağaçların sadece doğa varlığı değil, kültürel ve ruhsal anlam taşıyan simgeler olarak görülmesini ifade etmektedir.

Sonuç

Çalışmam, manevi uygulamaların, ritüellerin, değerlerin ve bitki-iletişiminin insanları ağaca ve onun yaşam alanına bütüncül bir biçimde bağladığını göstermektir. Modern tartışmalar çoğunlukla kaybolan geleneksel inanışlar ve maneviyatla bağlantılı yerli değer sistemlerinde bir değişimdir. Bu kültürel yapılar maneviyata bağlıdır; saygı, koruma ve gelecek nesiller için refahı pekiştirir. Biyoçeşitliliğin korunmasında geleneksel bilginin rolü açıktır.

Geleneksel uygulamaları ve ritüelleri sürdürürken geleneksel bilgi sahiplerinin koruduğu derin manevi bağ, bitki-insan ilişkilerine bağlı koruma uygulamalarının biyokültürel çeşitliliği artırabileceğine dair güçlü kanıt sunmaktadır. Bir kültür, kendini yalnızca maddi ifade veya politik tartışmayla değil, aynı zamanda davranışları yönlendiren ve bir kültürel uygulamadan daha derin ve kalıcı bir yaşantı sunan inanç sistemleri ve değerlerle

tanımlar. Maneviyatla ilgili sözlü gelenekler, efsaneler, mitler, şarkılar, ilahiler ve atasözleri gibi sözlü anlatımların yanı sıra ritüeller ve törenler çok çeşitli ifadeleri kapsar ve bir kültürü korumak için vazgeçilmezdir.
Bu araştırma; ağacın kutsal, mitolojik ve sembolik boyutları üzerinden, onun insanlık tarihi boyunca üstlendiği merkezi rolü ortaya koymayı hedeflemektedir. Çalışma, farklı uygarlıkların mitolojik anlatıları, ritüelleri ve sembolik pratikleri aracılığıyla ağacın kutsallığına yüklenen anlamları incelemekte ve bu anlamların kültürler arası benzerlik ve farklılıklarını karşılaştırmalı bir yöntemle değerlendirmektedir. Böylece, ağacın farklı toplumlarda nasıl algılandığı ve bu algının toplumsal, dini ve kültürel bağlamlarda ne tür işlevler üstlendiği derinlemesine ortaya konulmaktadır.

Kaynaklar

Anonim, (Tarihsiz). https://theconversation.com (Alıntı Tarihi: 14.08.2025)

Anonim, (2021). https://www.themarginalian.org/2021/10/26/why-leaves-change-color/

Kuş Şahin, C., Arslan, S., Onay, B. (2025). Ağaç İnancının Mitolojik Ve Kültürel Temelleri. Peyzaj Mimarlığı Konuları. *Yaz Yayınları*,2025. E_ISBN 978-625-5547-70-5

Lofgren, K. (2023). Plant Folklore: Myths, Magıc, And Superstıtıon. https://gardenerspath.com/plants/plant-folklore/

Rals, E., (2019). Meet Pando, one of the oldest organisms on Earth. https://www.earth.com/news/pando-oldest-organisms/

Sevindik, A., Kara, N.N. (2023). Anadolu Sahası Türk Masallarında Ağaç Kültü. 7th UBAK, 19 - 20 Ağustos 2023, Makale id= 96. Ankara

Sinha, P.K. (2024). Healing with the Energy of Trees: Ancient Wisdom and Cultural. *Perspectives*.2024. https://medium.com/@pritamkumarsinha/healing-with-the-energy-of-trees

Vyse, S. A. (2023). Believing in magic: The psychology of superstition. *Oxford University Press.*

Wohlleben, P. (2016). The Hidden Life of Trees. Penguin Random House India. (2016).

Vyse, S. A. (2023). Believing in magic: The psychology of superstition. *Oxford University Press*.

Pesticide residues in date palm and olive oil samples produced and consumed in Jordan

Skandar Abo Gazlah[1,2], Riadh Ilahy[3] and József Kiss[1]

[1]Laboratory of plant Protection, Faculty of Agricultural and Environmental Sciences, Horticultural Institute, Szent István University, 2100 Gödöllő Páter K. st.1, Budapest, Hungary
[2]Jordan Food and Drug Administration (JFDA)
[3]Department of Horticultural Crops, National Agricultural Research Institute of Tunisia, University of Carthage, Ariana, Tunisia

Abstract

The presence of pesticides in fruits and vegetables is becoming a growing concern not only for consumer but also for growers, processors and competent authorities in the entire world. In Jordan, there are only four specialized laboratories which have the required infrastructure to accurately determine pesticide residues in agricultural products. The aim of this study was to investigate the presence of PPPs residues in nationally produced palm dates and olive oil for local consumption and exportation. Among the283 pesticides analyzed, only 7 were detected in palm dates at concentrations ranging from detectable/quantifiable below the MRLs (4 µg/kg for carbendazim) to values above the MRLs attaining (508 µg/kg for carbendazim). Regarding olive oil, only 4 were detected at concentrations ranging from detectable below MRLs (20 µg/kg) for cypernethrin to higher than MRLs (260 µg/kg) for chloropyrifos. The order of occurrence for PPPs in date samples was from the greatest to the lowest as follows: carbendazim (53.33%), hexythiasox (21.3%), spiromesifen (12%), thiacloprid and finazinan (2.6%), thiophanate-methyl (6.6%), and imidacloprid (1.3%) and was in olive oil as follows: chloropyrifos (27.45%), cypermethrin (25.49%) and finally both oxyfluorfen and myclobutanil (3.92%). 84% of the date samples had pesticide residue lower than MRLs and only 16% had residue higher than MRLs. However, in olive oil samples, 49.01% had residue below the MRLs, 9.8% were above the MRLs and interestingly in 41.17% had no detected pesticide residues. The main part of the palm date tested samples (80.32%) were containing simple pesticide residue and (19.67%) exhibited double pesticide residue. However, in olive oil samples, only one of the reported pesticides was detected. Although the limited biological diversity (just one-year samples), we suggest, the urgent implementation of programs designed to facilitate awareness about the health concerns from PPPs and programming a compulsory and periodical training sessions for specialized workers and traders in Jordan.

Key Words: *Pesticide residues, date palm, olive oil, MRLs*

Introduction

The production of palm date and olive oil is considered as a strategic and primary sector for the Jordanian economy. In fact, in 2017, the Jordanian kingdom produced 25 222 tons of palm date fruits and 14 5073 tons of olive for both local and international markets (FAO Stat, 2019).

Fruits and vegetables consumption are increasing in the modern life style due to their content of natural antioxidants (Ilahy et al., 2018, 2020, Siddiqui et al., 2018). However, the improper use of PPPs (Plant Protection Products) might lead to increased risk of consumer health following high fruit and vegetables intake.

PPPs are also known as pesticides that protect crops or desirable or useful plants mainly used in the agricultural sector but also in forestry, horticulture, and in-home gardens. The PPPs contain at least one active substance and have numerous functions (European Commission for Food Safety, 2019).

Countries over the world are increasingly implementing new strategies to address improper PPPs usage and increase the food feed inspections and therefore safety along the exportation of agricultural commodities by as control laboratories and competent specialized authorities. Although the economic importance of palm date and olive oil sectors, palm date and olive oil trading are becoming increasingly hampered by MRLs (Maximum Residue Levels) exceedance for producing countries, including Jordan. Therefore, concerns are increasingly arisen in order to protect both local and international consumers. Previously, Algharibeh and AlFararjeh (2019) focused on pesticide residues in various fruits and vegetables gron and produced in Jordan using liquid chromatography/tandem mass spectrometry. However, palm date and olive oil were undertaken in this study although their primary importance for consumption and export traffic in Jordan.

Based on the above mentioned, the aim of this study was to perform a sampling of the main agricultural products in Jordan (palm date fruits and olive oil samples) from the main producing zones in the Kingdom and screening for the presence of 238 different pesticide active substance with respect to their MRLs using both LC-MS/MS and

GC-MS/MS analytical tools. This screening will be useful for suggesting urgent procedure or National plan to limit the excessive and the issue of plant protection products active ingredients. In addition, recent EU regulations (Sustainable Pesticide Use Directive) and principles in the document are discussed and considered in favour of improving palm oil and date consumers safety.

Materials and Methods

Laboratory working procedure
In 2018, the Jordanian Food and Drug Administration, performed a general check-up of various agricultural commodities for the presence of PPPs residues. For this purpose, 61 palm date fruits samples were gathered from different palm date producers in the Jordan Valley. The samples were accurately coded and delivered to the laboratory for further analysis to be screened for the presence of at least 283 pesticide active ingredient.
Solvents and reagents
The products used were all LC-MS grade Acetonitrile (MeCN), Toluene, 5% Formic acid solution in acetonitrile, Water, Methanol, Ammonium formate and Formic acid. Pesticide standards were purchased from Sigma Aldrich.
Sample preparation
Ready oil samples need no preparation and were stored immediately after reception and put in freezer at-20℃ or colder until analysis. However, for palm date, samples were weighed and the equivalent amount of LC-MS grade water was added then thoroughly homogenized and stored at -20℃ or colder and analyzed subsequently
Extraction procedure
Initially, 5 g of olive sample were weighed into a clean 50 mL tube. The blank samples were spiked at concentration 0.05 mg/kg and let further to stand for 10 minutes. Then 10 mL acetonitrile were added, and the mixture was vortexed for 1 min. The obtained extract was centrifuged at 5°C for 5 minutes at 6000 rpm then an aliquot of 6 mL of the acetonitrile phase (upper layer) was transferred into a 15 mL screw capped tube and placed at -20 ℃ or colder at least for 2 hours then the extract was centrifuge at 5°C for 5 minutes at 4000 rpm.

Clean-up procedure
For the clean-up procedure, 2 mL of the extract were filtered through 0.45 mm. For LC-MS/MS, a sample of 0.5 mL of the filtrate was acidified with 5% formic acid in acetonitrile (10 μL to every 1 mL). Then in in lab solutions software, the sample amount was set at 0.5 and the dilution at 1 so that the final extract is a concentration of ca. 0.5 g/mL.
Regarding GC-MS/MS a sample of about 0.5 mL of the filtrate was evaporated to almost dryness at 40 °C using a slight nitrogen flow (less than 5 bars) and reconstituted in 0.5 mL of toluene and mixed properly. The mixture was then acidified with formic acid 5% in acetonitrile (10 μL to every 1 mL) and in the Trace Finder software, conversion factor was set at 1 so that the final extract is a concentration of ca. 0.5 g/mL and then injected.

Analysis technique
Liquid Chromatography coupled with Mass Spectrometry-Mass spectrometry (LC-MS-MS)
HPLC-MS analyses were carried out using a Nexera (2040) LC system, Shimadzu. The chromatographic part was a Shimadzu 2040C chromatograph equipped with a Restek Raptor Biphenyl (100, 2.1mm, 2.7mm). The solvent A consisted of 2mmol/L ammonium formate + 0.002% formic acid-water mixture and the solvent B consisted of 2mmol/L ammonium formate + 0.002% formic acid methanol mixture. The volume injected by the automatic sampler/injector was 2µl with a flow rate of 0.4 ml/min under 35°C of column oven temperature. The gradient program started with 97% (A) and 3% (B) to attain in the middle of the run 0% (A) and 100% (B) and finish in the same conditions as initially indicated.
Regarding the MS conditions, the instrument used was an LC8050 system, Shimadzu with a nebulizing gas flow rate of 3L/min under an interface temperature of 350°C. The ionization mode was (ESI) and both the drying and heating gas flow rate was 10L/min.

Gas Chromatography coupled with Mass Spectrometry-Mass spectrometry (GC-MS-MS).
After extraction of pesticides that could be analyzed by gas chromatography were identified by GC-MS-MS coupling (Cheng et al., 2017). The chromatograph system was composed of a Trace 1310 Gas Chromatograph (Thermo Fisher Scientific- USA) equipped with TSQTM
Duo Triple Quadrupole Mass Spectrometer (Thermo Fisher Scientific- USA). Pesticides were separated with an RTX-5MS (30 m, 0.25 mm ID, 0.25µm) under the following conditions:
- Injector temperature: 250°C

- Split less injection: 2µl
- Column temperature: 90°C (hold 1min) 330°C at 8.5°C/min (hold 5 min)
- Carrier das: He (1.4 ml/min)

Regarding the MS conditions, the instrument used was an LC8050 system, Shimadzu with a nebulizing gas flow rate of 3L/min under an interface temperature of 350°C. The ionization mode was (ESI) and both the drying and heating gas flow rate was 10L/min. The results should always be reported and expressed in µg/kg (El-Saeid & AL-Dosari, 2010; Ferrer et al.,2005).

Results and Discussion

Date samples

As described in the Materials and Methods chapter, in 2018, the Jordanian Food and Drug Administration performed a general check-up of various agricultural commodities for the presence of PPPs residues. For this purpose, 61 palm date samples were gathered from different palm date producers in the Jordan Valley and 51 olive oil samples were gathered from olive oil producers in the region of Irbid located in the North of the Kingdom. The samples were accurately coded and delivered to the laboratory for further analysis to be screened for the presence of at least 283 pesticide active ingredients. Among the 283 pesticides that we have analyzed, only 7 were detected in palm date samples at concentrations ranging from detectable/quantifiable below the MRLs (Table 1) (4 µg/kg for carbendazim) to values above the MRLs attaining (508 µg/kg for carbendazim).

Table 1: LOQ and MRLs for different pesticide active substances detected in palm date fruit sample

Agricultural crop	PPPs active substance	LOQ (ppm)	MRLs (ppm)
Date palm fruit samples	carbendazim	0.05	0.1
	hexythiasox	0.093	2
	spiromesifen	0.003	0.02
	finazinam	0.02	0.01
	thiacloprid	0.01	0.01
	thiophanate-methyl	0.003	0.1
	imidacloprid	0.05	0.05

All the samples tested were positive for the presence of the residue for at least one active substance among the list of the following seven: carbendazim, hexythiasox, spiromesifen, thiacloprid, thiophanate-methyl, finazinam and imidacloprid). The other pesticides were not detected in all the palm date samples. However, it does not confirm complete freedom from pesticides since the other might be present but under instrumental detection (with respect to the used detection equipment).

The percentage of residues occurrence varied among the tested pesticide (Figure 1). In fact, the order of occurrence was from the greatest to the lowest as follows: carbendazim (53.33%), hexythiasox (21.3%), spiromesifen (12%), thiacloprid and finazinan (2.6%), thiophanate-methyl (6.6%), and imidacloprid (1.3%).

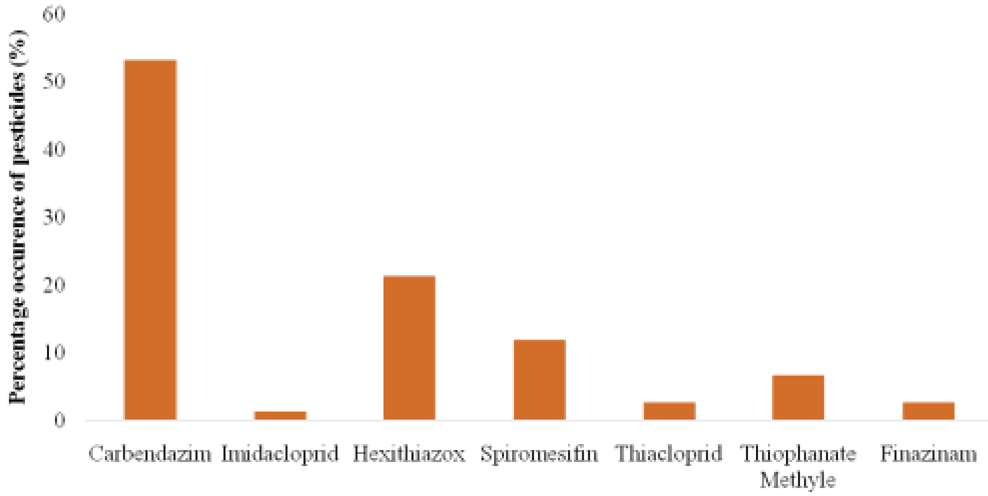


Figure 1: Percentage of occurrence of different detected pesticide active substances in date samples (2018, Jordan valley/ Random duplicate sample in each batch (20 samples/batch)

Among the palm date tested samples, 61 were positive, but also divided in samples with single and other with multiple pesticide residues. In our study, the main part of the tested samples (80.32%) were containing simple pesticide residue and others (19.67%) were samples with double pesticide residue (Figure 2). The result does not also confirm the absence of other pesticides in the tested samples since their presence might be not detected as hampered by instrumental LOD.

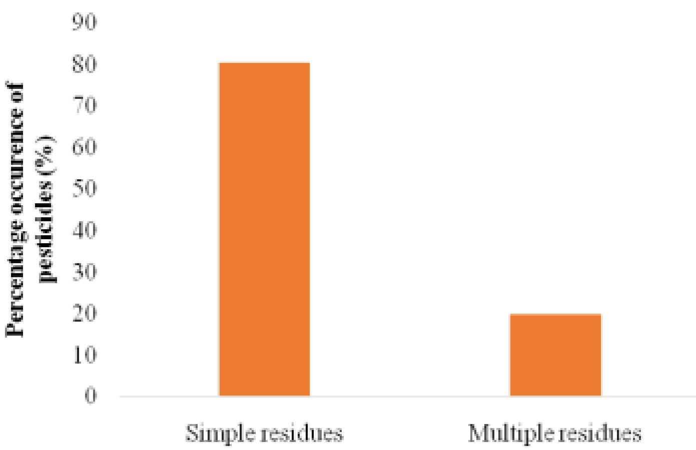


Figure 2: Percentage of occurrence of simple and multiple residues in date samples

Regarding the Maximum Residue Level, commonly known as MRLs, when data from all the palm date samples was considered, 84% of the samples had pesticide residue lower than MRLs and only 16% had residue higher than MRLs (Figure 3). Our values are similar to those of EL-Saeid and AL-Dosari (2010) who used different techniques for the analysis of various insecticide, fungicide, acaricide, and herbicide residues in three cultivars' of date fruits namely, Khalas, Sukkari, Nabout Seif as well their seeds. The authors reported that carbendazim was detected in samples of the three cultivars at 0.05, 0.04, and 0.03 ppm. Respectively, the residue level of cypermethrin in Khalas cultivars was 0.02 ppm (MRL 0.1 ppm). Cypermethrin was not detected in Sukkari cultivar but was detected in Nabout Seif at 0.03 ppm (MRL 0.01 ppm).

Additionally, the residue levels of both insecticides dimethoate and chlorpyrifos found in all the three sample date cultivars Khalas, Sukkari and Nabout Seif were higher three times compared with MRLs. Nevertheless, in this study also, glyphosate was detected in all three cultivars at the following levels 0.02, 0.02, and 0.03 ppm, respectively. The fungicide benomyl was detected in Khalas date samples only, and the residue level was 0.04 ppm. Carbendazim was detected in the three cultivars Khalas, Sukkari, and Nabout Seif (0.05, 0.05, and 0.03 ppm, respectively. Benomyl was detected in Khalas date samples (0.02 ppm).

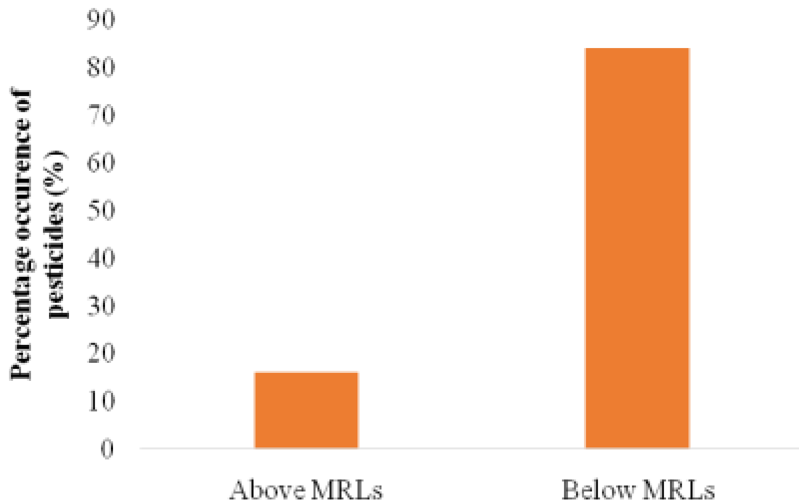


Figure 3: Percentage date samples below or above MRLs

Olive oil samples

A total of 51 olive oil samples were gathered from olive oil producers in the region of Irbid located in the North of the Kingdom. The samples were accurately coded and delivered to the laboratory for further analysis to be screened for the presence of at least 283 pesticide active ingredients.

Among the 283 pesticides tested, only 4 were detected at concentrations ranging from detectable below MRLs (20 µg/kg) for cypernethrin to higher than MRLs (Table 2) (260 µg/kg) for chloropyrifos.

Table 2: LOQ and MRLs for different pesticide active substances detected in olive sample

Agricultural crop	PPPs active substance	LOD (ppm)	MRLs (ppm)
Olive oil samples	chlorpyrifos	0.01	0.25
	cypermethrin	0.01	0.25
	oxyfluorfen	0.02	5
	myclobutanil	0.01	0.1

The pesticide residue was not detected in all olive oil samples. In fact, 49.01% of the samples had residue below the MRLs, 9.8% were above the MRLs. Interestingly, in 41.17% of the tested olive oil samples, no pesticide was detected. However, it does not confirm totally the absence of pesticide residues since other might be present but under LOD for the used analytical procedure (Figure 4)

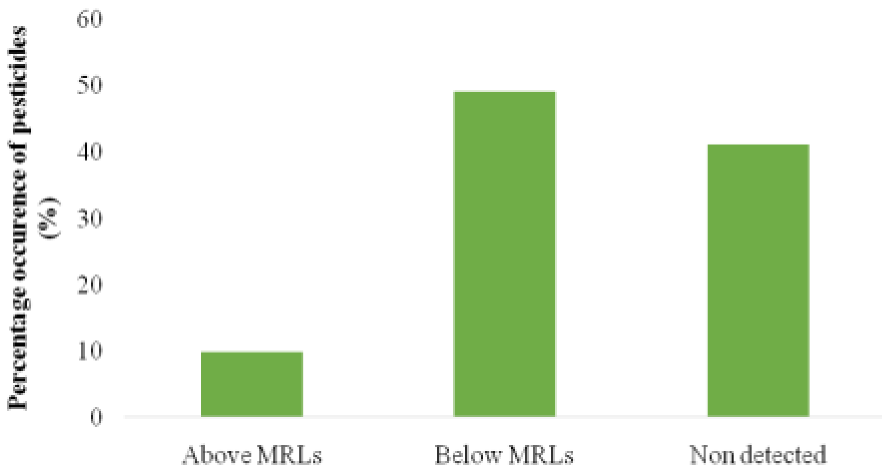


Figure 4: Percentage olive oil samples below or above MRLs and free pesticides samples

The percentage of residues occurrence varied among the 4 pesticide (Figure 5). In fact, the order of occurrence was from the greatest to the lowest as follows: chloropyrifos (27.45%), cypermethrin (25.49%) and finally both oxyfluorfen and myclobutanil (3.92%).

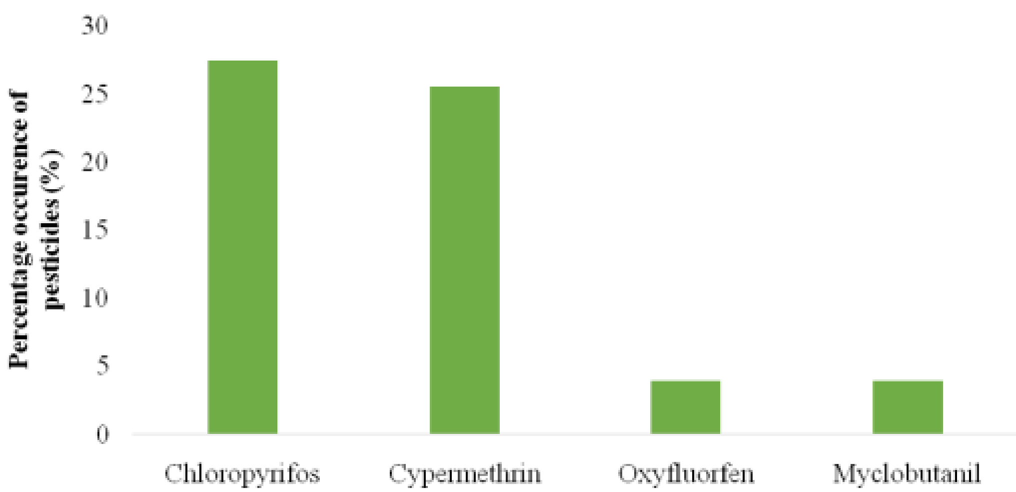


Figure 5: Percentage of occurrence of different detected pesticides active substances in olive oil samples (Irbid/ Random duplicate sample in each batch (20 samples/batch)

Our results (20-80 microgram/kg fw for cypermethrin) were close to the lowest value reported by Ferrer et al. (2005) who focused on the occurrence of various widely used pesticides (dimethoate, simazine, atrazine, diuron, terbuthylazine, methyl-parathion, methyl-pirimiphos, endosulfan I, endosulfan II, endosulfansulphate, cypermethrin and deltamethrin), which can be found at trace levels in olive oil and olives and detected cypermethrin concentrations ranging between 25–500 microgram/kg fw. (One should notice that the vaste majority of the above listed active substances are not registered (anymore) on the EU market). Regarding chloropyrifos, Likudis et al., (2014) reported a mean value for this pesticide attaining 32.9 microgram/kg fw which was also in the range of the values (50-650 microgram/Kg fw) reported in this study.

Acknowledgements

This study was kindly supported by Jordan Food and Drug Administration (JFDA) fas well as all the technical staff of the Laboratory of plant Protection, Szent István Campus, Hungarian University of Agriculture and Life Sciences, Hungary is warmly acknowledged.

References

Algharibeh GR, & AlFararjeh MS. 2019. Pesticide residues in fruits and vegetables in Jordan using liquid chromatography/tandem mass spectrometry. Food Additives & Contaminants: Part B, 12(1):65-73.

Algharibeh GR, & AlFararjeh MS. 2019. Pesticide residues in fruits and vegetables in Jordan using liquid chromatography/tandem mass spectrometry. Food Additives & Contaminants: Part B, 12(1):65-73. https://doi.org/10.1080/19393210.2018.1548505

Cheng Z, Dong F, Xu J, Liu X, Wu X, Chen Z, ... & Zheng Y. 2017. Simultaneous determination of organophosphorus pesticides in fruits and vegetables using atmospheric pressure gas chromatography quadrupole-time-of-flight mass spectrometry. Food chemistry, 231: 365-373. https://doi.org/10.1016/j.foodchem.2017.03.157

El-Saeid MH, & AL-Dosari SA. 2010. Monitoring of pesticide residues in Riyadh dates by SFE, MSE, SFC, and GC techniques. Arabian Journal of Chemistry, 3(3):179-186. https://doi.org/10.1016/j.arabjc.2010.04.007

Ferrer C, Gómez MJ, García-Reyes JF, Ferrer I, Thurman EM, & Fernández-Alba AR. 2005. Determination of pesticide residues in olives and olive oil by matrix solid-phase dispersion followed by gas chromatography/mass spectrometry and liquid chromatography/tandem mass spectrometry. Journal of Chromatography A, 1069(2):183–194. https://doi.org/10.1016/j.chroma.2005.02.015

Ilahy R, Tlili I, Pék Z, Montefusco A, Siddiqui MW, Homa F, ... & Lenucci MS. 2020. Pre-and post-harvest factors affecting glucosinolate content in broccoli. Frontiers in Nutrition, 7:147. https://doi.org/10.3389/fnut.2020.00147

Likudis Z, Costarelli V, Vitoratos A, & Apostolopoulos C. 2014. Determination of pesticide residues in olive oils with protected geographical indication or designation of origin. International Journal of Food Science & Technology, 49(2):484-492 https://doi.org/10.1111/ijfs.12326

Ilahy R, Siddiqui MW, Tlili I, Montefusco A, Piro G, Hdider C, & Lenucci MS. 2018. When color really matters: horticultural performance and functional quality of high-lycopene tomatoes. Critical Reviews in Plant Sciences, 37(1), 15-53.484-492. https://doi.org/10.1080/07352689.2018.1465631

Siddiqui MW, Lara I, Ilahy R, Tlili I, Ali A, Homa F, ... & Hdider C. 2018. Dynamic Changes in Health-Promoting Properties and Eating Quality During Off-Vine Ripening of Tomatoes. Comprehensive reviews in food science and food safety, 17(6):1540-1560. https://doi.org/10.1111/1541-4337.12395

Implementing AI Agents for Strategic Transformation in Agriculture

Zeynel Cebeci [1]

[1]Department of Animal Science, Faculty of Agriculture, Çukurova University, Adana, Türkiye

Abstract

This paper focuses on the application of Artificial Intelligence agents (AI agents) in smart farming, highlighting their potential to drive strategic transformation across agricultural prodction systems. It introduces a general framework for AI agent implementation, emphasizing a problem-specific design that integrates wearable IoT sensors, computer vision, and cloud-based analytics to enable data-driven decision-making. A detailed case study on estrus detection in dairy cows demonstrates this framework in practice. For this task, a traditional Random Forest (RF) model and a Reinforcement Learning (RL)-based Q-learning agent were employed and compared on simulated data. While the overall accuracy metrics of both models were very similar, the RF model demonstrated higher potential by prioritizing the correct classification of non-estrus cases. In contrast, the RL agent delivered a more balanced and practically successful approach in the simulated environment. The RL agent's success is attributed to a carefully designed reward structure that effectively balances detection sensitivity with the need to minimize operational costs from false alarms. Our findings from simulated data once again validate the transformative potential of AI agents in addressing critical agricultural challenges, from reproductive management to resource optimization. The study also emphasizes the importance of ethical design, farmer-centric interfaces, and scalable deployment strategies for real-world applications.

Key Words: *Artificial Intelligence Agents, Machine learning, Reinforcement learning, Estrus detection, Animal monitoring, Precision farming*

Introduction

An agent is something that perceives its environment and acts to achieve a goal. Formally, an Artificial Intelligence agent (AI agent or AIA) is an intelligent computational system designed to operate in different levels of autonomy to make decisions, learning and adaption (Wooldridge & Jennings, 1995; Rudowsky, 2004; Obeidat et al., 2024). As shown in Figure 1, AI agents perceive stimuli (e.g., signals data, images, sounds, texts, codes) via sensors, cameras or other data collectors; process data using algorithms (e.g., data preprocssing, machine learning models), and execute goal-directed actions (e.g., controlling robotic arms, switching ventilation systems, sending messages, trigerring some events). In summary, intelligent systems encapsulate the core principles of artificial cognition, functioning through a tripartite operational paradigm of sensing, reasoning, and acting. As a well-known example, an autonomous tractor can be considered as an agricultural AI agent. It perceives its environment using various sensors, drones, and GPS technology to gather pyhsical and location data for crops. The collected data is then processed using machine learning algorithms and nutrient analysis to make decisions about the most efficient actions to take. Finally, the tractor acts by applying resources through robotic sprayers or variable-rate application techniques, adjusting the amount of fertilizer or pesticide based on the data analysis. This entire process can be carried out autonomously, improving productivity and resource efficiency without human intervention.

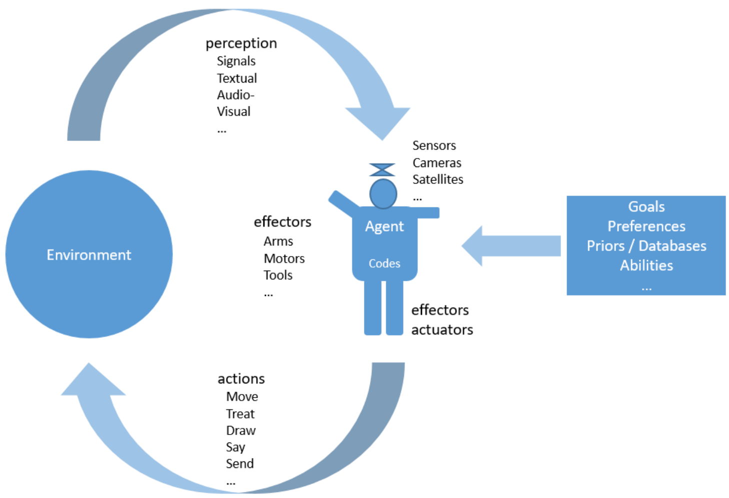


Figure 1. Basic structure of an AI agent

AI agents do not always have to manifest in a specific form such as the autonomous agricultural tractor mentioned above. They can appear in various forms and serve diverse tasks o goals, each equipped with customized capabilities tailored to different environmental interactions and decision-making processes. As above mentioned, agents are systems with advanced sensing, reasoning, and acting capacities, enabling them to operate in various environments. AI agents demonstrate versatile applicability across multiple application domains, each characterized by distinct environmental interactions and decision-making approaches. In autonomous systems, these agents manifest as sophisticated control architectures enabling self-navigation in complex environments. Autonomous vehicles exemplify this category, employing multimodal fusion of sensors and vision tools (e.g., cameras, LIDAR, radar) coupled with reinforcement learning algorithms to achieve real-time path planning and obstacle avoidance. Similarly, unmanned aerial vehicles leverage these capabilities for applications ranging from precision delivery to infrastructure inspection (Luo et al., 2002).

Production or industrial environments increasingly deploy AI agents through robotic process automation works, which automate rule-based business processes with unprecedented precision. These systems combine computer vision for interface interaction with decision trees for workflow management, demonstrating particular efficacy in high-volume transactional environments such as financial reconciliation and customer service operations.

Predictive modeling constitutes another major application domain, where AI agents employ statistical learning techniques to forecast system behaviors. In agricultural domain, these models process multispectral imaging data and soil sensor inputs to generate yield predictions with quantifiable confidence intervals. Financial implementations similarly analyze market trends and patterns through time series data analysis and deep learning models to inform trading strategies.

The intelligent virtual assistants represents another significant application area, where natural language processing architectures enable conversational interfaces. These systems integrate speech recognition, intent classification, and knowledge graph traversal to provide context-aware responses and task execution. Their operational efficacy forms from continuous learning mechanisms that adapt to user preferences and linguistic patterns through iterative interaction.

The fundamental characteristic unifying these diverse applications is the agents' capacity for environmental interaction through perceptual inputs, cognitive processing via machine learning architectures, and adaptive response generation. This tripartite operational paradigm enables continuous performance optimization through experiential learning, with the specific implementation architecture varying according to domain requirements and environmental constraints.

These technological advancements represent more than just improvements in efficiency. They are fundamentally changing human relationship with the natural world. By providing unprecedented visibility into environmental conditions and offering predictive insights into future risks, AI agents are enabling a proactive approach to resource management. This shift could play an important role in addressing some of the most pressing ecological challenges in recent decades. As these systems continue to evolve, their potential to support a more sustainable coexistence between human activity and natural ecosystems will only grow stronger.

AI agents have already started to transform agricultural production and natural resource management by providing intelligent automation and data-driven decision-making capabilities. For example, autonomous tractors navigate fields using real-time sensor data, while drone-mounted cameras scan crops for early signs of disease or nutrient deficiencies. Advanced algorithms analyze satellite and camera images and weather patterns to optimize irrigation schedules and predict yields with high accuracy. All these reduce the usage water and chemical inputs while maximizing productivity. In this way, farmers can improve farm yields while reducing input costs, and enhancing agribusiness operations.

The primary objective of this paper is to demonstrate a general framework for AI agent design and implementation, using a specific, high-impact application: automated estrus detection in dairy cows. The study mainly focuses on a comparative analysis of two distinct machine learning approaches: a traditional supervised learning approach with a Random Forest model, and a Q-learning approach with a Reinforcement Learning (RL) agent. By simulating sensor data rather than collecting it directly, we aim to focus our analysis on the agent's computational intelligence, or "brain," and how it learns from data to make optimal decisions. By detailing the development and evaluation of these models on simulated data, it is aimed to provide actionable insights for researchers and practitioners, showcasing how AI agents can be tailored to address complex agricultural challenges and drive strategic transformation.

Types and Architecture of AI Agents

AI agents can be categorized in various ways based on their application domains, autonomy levels, cognitive architectures, learning capabilities, ethical frameworks, and more. Below are some main categories of agents according to these 12 dimension presenting a better understanding of the complex world of AI agents. The taxonomy below offers a multidimensional view which captures the fact that AI agents are rarely limited to one category. It is comprehensive, logical, and multi-dimensional, allowing for a deep and nuanced description of almost any AI agent. The novelty of this approach lies in the unique combination of many dimensions, particularly the inclusion of Professional Roles and Data Sources as distinct, high-level categories. This framework is not just a list; it is a powerful tool for analyzing, designing, and discussing AI agents. It provides a shared vocabulary that can be used by researchers, developers, and practitioners to clearly define the capabilities and characteristics of different AI systems.

Based on Physical Presence
1.Software agents (non-pyhsical)
2.Robotic agents (embodied)
3.Swarm agents (physical colonies, software bots)
4.AR/VR agents (embodied conversational)

Based on Cognitive Architecture
1.Reactive agents (Brooks Subsumption Architecture)
2.Symbolic/Deliberative agents (GOFAI Approach)
3.Deep Learning-Based Neural agents
4.Neuro-Symbolic Hybrid agents
5.Belief-Desire-Intention (BDI) agents

Based on Degree of Autonomy
1.Fully Human-Controlled
2.Semi-Autonomous agents (Human-in-the-loop)
3.Fully Autonomous agents
4.Super-Autonomous agents (Self-Goal Setting)

Based on Number of Agents
1.Single agents
2.Multi agents

Based on Learning Ability
1.Static (Rule-Based)
2.Online Learning agents (Reinforcement Learning + Online data)
3.Offline Learning agents (ML with batch data)
4.Meta-Learning agents (Few-Shot learning)
5.Self-Improving agents (AutoML, Self-Play)

Based on Time Perspective
1.Instant Reactive agents
2.Short-Term agents (Planner)
2.Long-Term agents (Strategist)
3.Temporal Holistic agents (Temporal Reasoning)

Based on Computational Paradigm
1.Classical computational agents
2.Quantum agents
3.Neuromorphic agents (biologically inspired)
4.Distributed agents (blockchain-based)
5.Edge agents (edge computing)

Based on Professional Roles
1.Customer agents
2.Employee agents
3.Coding agents

4.Data mining agents
5.Creative/Designer agents
6.Security agents

Based on Data Sources
1.Database-centric agents
2.Environment-centric agents (robotic agents, game AIs)

Based on Application Domain
1.Industrial agents (manufacturing, logistics)
2.Medical agents (diagnosis, treatment)
3.Financial agents (trading reccommendations, risk management)
4.Ecological agents (monitoring forest fires and water reservoirs)
5.Cyber agents (cyber security, network monitoring)

Based on Social Interaction
1.Isolated agents (Single agents)
2.Competitive agents (multiple game theory-based)
3.Cooperative agents (multiple team-based)
4.Organizational agents (multiple corporate hierarchies)
5.Social agents (human-interactive, interactive partners)

Based on Ethical and Safety Considerations
1.Rule-Based Safety agents
2.Value-Aligned agents
3.Risk-Aware agents
4.Controllable agents
5.Explainable (XAI) agents
6.Fair / Unbiased agents
7.Secure agents

Today, the AI agents typically exist at the intersection of several of these dimensions rather than simply categorizing them along a single dimension. For example, one could describe an agent as a "fully autonomous, neuro-symbolic, risk-aware, environment-centric medical agent". As another example for agriculture, an autonomous tractor can belong to multiple categories such as neuro-symbolic hybrid architecture, online learning capabilities, semi-autonomous modes, physical embodied presence, social interaction in traffic, long-term route planning, responsible AI category and industrial application domain. The selection of agent architecture depends critically on the application domain's characteristics which includes environmental dynamics, observability, and performance requirements. Contemporary research increasingly focuses on hybrid architectures that combine multiple paradigms, particularly integrating learning capabilities with traditional symbolic reasoning approaches. This evolution reflects the growing recognition that complex real-world applications often require agents that can simultaneously exhibit rapid response, long-term planning, and adaptive learning capabilities. The architectural choice fundamentally determines the agent's capacity for handling uncertainty, adapting to change, and scaling to complex problem spaces.

An AI agent's architecture can have varying complexities based on the taxonomy provided above. As an implementation example application to give an idea, a livestock health monitoring system generally consists of the following components. Modern livestock farming faces challenges in early disease detection, breeding efficiency, and stress management. Traditional methods rely on manual observation, which is labor-intensive and often detects issues too late. AI-powered wearable sensors and computer vision systems enable real-time monitoring of animal health, behavior, and physiological states, improving welfare and farm productivity.

IoT Sensors
Wearable biometric trackers (collars, ear tags, or leg bands) monitor:
Heart rate, respiration, temperature (estrus and early illness detection)
Rumination and feeding activity (digestive health)
Movement patterns (lameness, stress, aggresivity)
BLE/WiFi/LoRa transmits data to a central AI analytics platform
AI-Enabled Computer Vision
Overhead cameras or drones capture:

Gait analysis (detecting lameness via pose estimation)
Facial/body condition scoring (nutritional status)
Social interactions (identifying aggression or isolation)
Thermal cameras (detecting fever or inflammation)
Cloud-Based AI Analytics
Machine Learning models process sensor and vision data to:
Predict disease outbreaks (e.g., mastitis, foot rot)
Detect estrus cycles (optimizing breeding timing)
Identify stressors (heat, overcrowding)
Communication and Storage
Inputs are received by farmers or other components and agents
Alerts are sent to farmers via mobile apps and farm management systems
When we combine the above listed components within a system architecture, we can create the general architecture shown in Figure 2. This basic architecture covers various aspects of real-time data processing, decision-making, communication, and execution, demonstrating a sophisticated approach to managing farms. The architecture is split into distinct layers, each with a specific role, which adds flexibility and scalability to the system. For example, the separation of edge processing and cloud analytics helps meet low-latency and high processing power requirements. The modular microservices design also facilitates easy updates and changes to sensors or algorithms. This modularity ensures the system's long-term sustainability and adaptability.

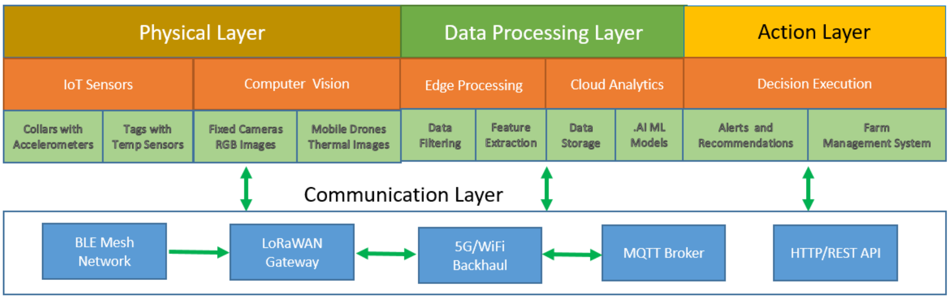


Figure 2. General architecture of a livestock monitoring agent

Physical Layer is the starting point to collect data from environment. This layer uses a variety of wearable IoT sensors (collars, ear tags, leg bands), each designed to monitor specific animal health metrics. The sensors provide real-time data on movement (e.g. via accelerometers), temperature (via temperature sensors), and rumination (via acoustic sensors). These recorded data are critical for tracking the health of animals continuously. In addition, the vision systems (including fixed RGB + depth cameras and drone-mounted thermal cameras) provide a more detailed view of the behavior and health of animals. The combination of thermal and RGB cameras provides deeper measurements of behavioral changes that might indicate health problems.

In Data Processing Layer, edge processing is used to reduce latency by performing preliminary data filtering and compression. This ensures that the system can act on the data almost in real time. TinyML models enable local inference, sending alerts or making predictions at the edge without relying on cloud processing for every decision. This can be applied for low-latency responses. On the cloud analytics side, time-series databases handle the large volumes of sensor data, while deep learning models can be used for predictions and long-term trend analysis. Computer vision pipelines, using algorithms like CNN and YOLO, help with behavioral detection, adding another layer of insight into livestock monitoring.

The Action Layer ensures that once the data has been processed and analyzed, appropriate actions are taken. This includes alert prioritization engines, automated reporting, feeding and treatment system integration. Critical issues are flagged and notified immediately, while routine alerts are reported in daily digests by the first component. The system integrates with farm management software, providing links between the monitoring system and farm operations. Alerts can trigger automatic adjustments in feeding or veterinary treatment based on detected health issues.

The Communication Layer uses a hybrid network topology, which is key to ensuring data transmission between sensors and cloud systems. The use of Bluetooth Low Energy (BLE) mesh networks for wearable-to-gateway communication, Long Range Wide Area Network (LoRaWAN) for long-range data transmission, and 5G/WiFi for high-bandwidth applications (e.g., video streaming) ensures that the system can handle various data transmission requirements. Additionally, the use of Message Queuing Telemetry Transport (MQTT) and

HTTP/REST APIs provide protocol bridges for interoperability, making it easier to integrate the system with other platforms or farm management tools and systems.

Data flow and alert component of an agent allows smooth processing and decision-making using data. For example, sensors collect biometric data every 2-15 seconds. Edge nodes filter and compress the data before sending it to the cloud. The cloud performs multimodal data fusion (sensors + vision data) to provide a complete task. Machine learning models generate predictions and identify changes and anomalies. Alerts are routed based on severity, with critical issues being flagged for immediate action (SMS or Apps' notification), and routine issues reported in scheluded times. This structured data flow ensures that all data is processed in a timely manner, and the appropriate actions are taken based on the urgency of the situation. While the architecture emphasizes the technical side of monitoring, a more interactive and intuitive UI would help farmers quickly interpret complex data and take appropriate action. The machine learning models should be continuously updated with new data to keep the system effective. For example, the system could employ active learning techniques to learn from new anomalies and improve prediction accuracy over time. Given the sensitive nature of animal health, the system should consider integrating ethical guidelines to ensure that interventions made by the AI are both scientifically sound and morally acceptable.

In addition to the technical aspects of the systems, privacy and security feature is also especially important in agricultural contexts, where privacy concerns about personal and sensitive data may arise. This feature ensures that data privacy is maintained without compromising the system's effectiveness. Morover, on the Integration and usability aspect, the system design ensures that the platform is user-friendly. The integration with farm management software and the modular approach to adding or updating sensors and algorithms provides an experience for farm operators. Furthermore, the alerts and reports are delivered in a format that can be easily understood and acted upon, helping farm managers make better decisions.

A Case Study: Estrus Detection Agent

Estrus, also commonly called "heat," is the short period within a female's reproductive cycle during which mating is most likely and conception can occur. This period is characterized by an increase in estrogen levels, which drives observable behavioral and physiological changes signaling the female's readiness to mate. While the duration, cues, and hormonal trajectories of estrus can vary across species, hormonal and environmental cues coordinate to elicit breed-signaling behaviors and corresponding physiological states.

Key signs of estrus can vary by species, but common indicators include standing to be mounted where the female in "standing heat" will allow a male or other females to mount without moving away. Additional physiological cues include an increase in body temperature, milk progesterone level, and changes in the vulva, which may appear swollen, red, and moist, and, in some cases, a clear, sticky mucus discharge observable from the vulva. Detecting estrus is critical task for managing animal reproduction, especially in livestock. By monitoring the signs of estrus, such as restlessness, vocalization, or standing to be mounted, breeders can determine the optimal time for natural mating or artificial insemination.

As reviewed in many studies, numerous research has been conducted on various aspects of applications and electronic technologies for detecting estrus in dairy and beef cattle husbandry (Mičiaková et al, 2018; Reith & Hoy, 2018; Roelofs & Van Erp-van der Kooij, 2018; Santos, 2022; Sharifuzzaman et al, 2024; Merkelytė et al, 2025). Delwiche et al (2001) compared estrous cycle by online measurement of milk progesterone and to evaluate the potential for detection of ovulatory events versus standard estrus detection methods. Rorie et al (2002) studied on the practibility and laboring costs of various technologies such as pedometers, accelometers, intravaginal sensors, and imaging devices. They stated that the mount monitors have the broadest application while imaging as lower performing, and intravaginal resistance measurement as the least practical method of estrus detection. Talukder et al. (2014) investigated an infrared thermography device to predict cows in estrus and about to ovulate. Andersson et al (2016) presented and tested an in-situ estrus detection research with a wireless intravaginal probe for cattle capable of automatizing the process based on measurements of conductivity and temperature as well as movement sensing, and reported higher performance. Reith and Hoy (2018) pointed that estrus detection based on sensor-supported activity monitoring, especially accelerometer systems has been the most practical method.

As understood in the studies above, various instruments and tools have been developed and are in use. Some recent studies have been focused on machine learning in estrus detection. For instance, Wang et al (2020) aimed to combine location, acceleration, and machine learning to detect estrus in dairy cows. A neck-mounted device on 12 cows over 12 days, measuring 12 behavioral metrics like standing, lying, and walking duration. Four machine learning models (KNN, BPNN, LDA, and CART) were tested to identify estrus. Wang et al.(2022) developed an improved YOLOv5 model to address the challenge of detecting cow estrus in complex natural environments. Their method, which enhanced the model's ability to handle multi-scale objects and varying conditions, achieved a high average accuracy of 94.3% and an inference speed of 71 fps. This impressive performance demonstrates the model's effectiveness and suitability for fast and accurate estrus detection in real-world, large-scale settings. Lodkaew et al (2023) designed CowXNet, an automatic estrus detection system based on YOLOv4 and CNN using camera images wih a performance rate 83%. However, still there is a need for new approaches and applications based on AI agent architecture. Implementing IoT-based AI agents to detect estrus can significantly reduce detection time and operational costs, leading to substantial improvements in efficiency and productivity in livestock farming. For example, sensor networks can monitor activity, temperature, and hormonal proxies, while AI analyzes patterns to flag estrus events in real time, enabling timely insemination decisions for a better herd management.

Conceptually, an AI estrus detection agent operates through the integration of three main interdependent layers such as data collection, data processing, and decision-making. In the first layer, various sensors collect real-time data from animals and their environment. Accelerometers monitor activity levels, capturing increased movement typically associated with estrus. Body temperature is tracked using thermal cameras or implanted sensors to detect physiological changes. Pressure sensors identify mounting behavior, a strong indicator of reproductive readiness. GPS modules are used to monitor herd movement patterns and spatial behaviors, while acoustic sensors analyze vocalizations for changes in frequency and intensity. Additionally, camera systems record visual cues such as facial expressions, vulva swelling and discharge which are subtle but important indicators of estrus.

Table 1. Examples of AI/ML Models in Estrus Detection

Model	Purpose	Uses
GRU, LSTM	Time series movement data analysis	Capturing long-term dependencies
kNN, CART, CHAID, SVM, RF, XGBoost, LightGBM, CatBoost, CNN, etc.	Classifying sensor data	Feature importance analysis
YOLOv8	Detecting facial and vulva changes in images	Real-time object detection
Autoencoder	Anomaly detection	Working with unlabeled data

Once collected, the data is processed using a suite of AI and machine learning models, some of which are listed in Table 1. Time-series models like LSTMs and GRUs are particularly effective in analyzing sequential movement and temperature data to identify trends over time. Convolutional Neural Networks (CNNs), including real-time detection models like YOLOv9 (Yaseen, 2024), are employed to analyze visual inputs and detect physical changes indicative of estrus. For behavioral anomalies that may not follow a clear pattern, unsupervised learning techniques such as autoencoders and Isolation Forests are used to detect deviations from normal behavior. These varied data streams are combined through sensor fusion models, allowing the system to produce a context-aware, holistic assessment of each animal’s reproductive state.

The decision-making layer interprets the processed data using both rule-based thresholds and probabilistic reasoning. By evaluating patterns such as heightened activity, elevated temperature, and mounting behavior, the system calculates an estrus probability score. When this score exceeds a defined threshold, alerts are generated through multiple channels. Farmers can receive real-time notifications via SMS or messaging apps like Whatsup, Intagram or Telegram. The system also integrates with farm management software to update records and support scheduling of reproductive interventions. On-site alerts may be delivered through visual cues such as LED indicators to facilitate immediate action.

Working with Traditional Machine Learning Models

Instead of detailing the full spectrum of hardware and software components of an estrus detection agent, this paper focuses on an agent's learning component using a classifier for estrus detection. The aim is to offer actionable insights for newcomers, including data preprocessing steps, feature selection (e.g., activity measurements, body temperature changes etc.), model training and evaluation strategies, and practical considerations for implementing a robust and interpretable ML-based detection agent. In this study, a Random Forest (RF) machine learning algorithm was implemented in the R environment (R Core Team, 2025) to train and evaluate a model for estrus detection in dairy cattle (in Supplementary Code 1). The first part of the code generates data for 200 dairy cows through simulation. In the data simulation the predictors were locomotion activity, body temperature, and number of mounts. Estrus expression in dairy cows was simulated using three sensor-derived data that are commonly employed in commercial herd monitoring systems. Locomotor activity was generated from collar-mounted accelerometers, expressed in arbitrary activity units per hour (AU h^{-1}), with estrus periods characterized by a relative increase of approximately 30–40% above baseline levels. Body temperature was modeled based on data from collar-integrated temperature loggers, assuming a physiological baseline of 38.5 °C and a transient rise of 0.3–0.5 °C during estrus. Mounting behavior was represented by counts from leg-mounted pressure sensors (mount detectors), with values drawn from a Poisson distribution to capture the stochastic nature of mounting events. The relevant parameters were configured as compatible to both physiological and behavioral variability reported in the literature (Redden et al., 1993; At-Taras & Spahr, 2001; Roelofs, 2005; Suthar et al., 2011; Yin et al., 2013; Wang et al., 2020; Stevenson, 2021; Kim et al., 2023; Mičiaková et al., 2024), thereby improving the biological validity of the simulation.

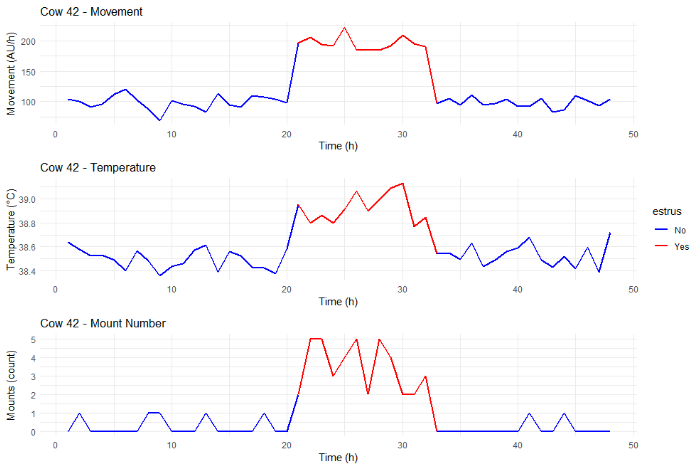


Figure 3. Time-series profiles of simulated estrus indicators for a cow over a 48-h monitoring period

As an example, Figure 3 shows the time-series plot of simulated estrus indicators for a cow over a 48-h monitoring period. In the figure, (A), (B), and (C) represent locomotion activity (AU/h), body temperature (°C), and mount counts per hour, respectively. Blue segments indicate show non-estrus periods, while red segments indicate estrus periods as defined by the simulation model. In data simulation, three estrus-related states were incorporated into the model: (i) *normal estrus*, with concordant increases in activity, temperature, and mounting frequency; (ii) *silent estrus*, where temperature showed only a modest rise without parallel increases in activity or mounting; and (iii) *pseudo-estrus*, characterized by artificially increased mounting counts due to behavioral mimicry in the absence of activity or temperature changes. In the simulation, the incidence of silent estrus was set at 15%, reflecting the range of 7% to 40% reported in the literature (Bharali et al., 2019; Zduńczyk et al., 2005). The occurrence of false estrus (pseudo-estrus), which can result from false-positive activity alerts, was set at 10%, which is conservative compared to reports of false detection rates reaching up to 50% in activity-based estrus detection systems (Kennedy & Ingalls, 1995).

Once simulation data generated, it was divided into training (80%) and testing (20%) subsets using stratified sampling to preserve the proportion of estrus and non-estrus cases. The training set was then used to develop a Random Forest classification model with 200 decision trees, where estrus status was predicted based on three features: locomotion activity (movement), body temperature, and the number of mounts recorded (mount_count). Variable importance was also calculated to assess the relative contribution of each predictor to estrus detection. In Figure 4, the variable importance measures derived from the Random Forest model are presented. The left panel (Mean Decrease Accuracy) indicates that movement was the most influential predictor for maintaining classification accuracy, followed by temperature, whereas mount number contributed the least. Conversely, the right panel (Mean Decrease Gini) highlights temperature as the strongest predictor in terms of reducing node impurity, with movement ranked second and mount number again showing the lowest importance. Taken together, these results suggest that both physiological (temperature) and behavioral (movement) indicators provide robust information for estrus detection, while mount number alone appears less reliable in this simulated dataset.

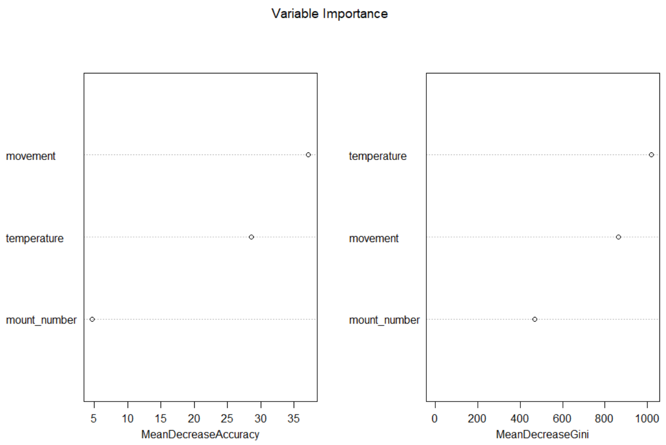


Figure 4. Variable importance plots

In order to assess the predictive performance of the Random Forest model on the independent test set, a confusion matrix and receiver operating characteristic (ROC) curve were given in Figure 5.

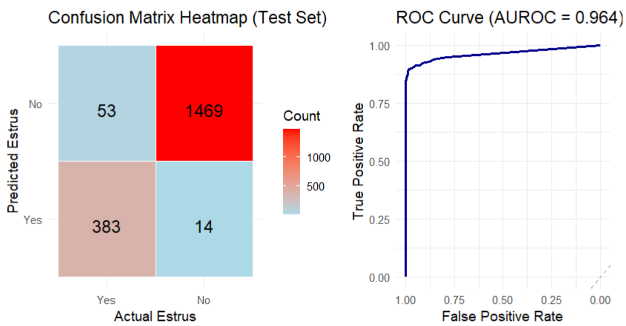


Figure 5. Confusion matrix heatmap and ROC curve for test data

In Figure 5, according to the ROC curve plotted using the predicted probabilities of estrus, the high area under the curve (AUROC= 0.964) indicated a strong overall discriminatory capability of the model across various thresholds. The classification model exhibits robust performance with a high overall Accuracy of 96.51% and a statistically significant improvement over the No Information Rate, validated by a p-value less than 2.2e-16. The model demonstrates exceptional performance in correctly identifying the 'No' (non-estrus) class, as indicated by a Sensitivity of 99.06%, while maintaining a high Positive Predictive Value (Precision) of 96.52%. However, the Specificity for the 'Yes' class (estrus case) is comparatively lower at 87.84%, and a significant disparity between false positives (14) and false negatives (53) is confirmed by McNemar's Test ($p < 3.443e-06$), suggesting the model is more prone to missing positive cases than to making incorrect positive predictions. The high Kappa statistic of 0.8973 confirms a strong level of agreement beyond.

Working with Reinforcement Learning Models

Reinforcement Learning (RL) is an AI paradigm within machine learning where an autonomous agent acquires a policy for action selection through direct interaction with a dynamic environment. Unlike supervised learning as demonstrated with the example of RF modeling above, RL operates without explicit labels or predefined data patterns, instead learning from the consequences of its own actions. The core objective of an RL agent is to learn an optimal goal or policy that maximizes the cumulative sum of rewards over a given time horizon.

The fundamental components of an RL system are:

Agent is a decision-making entity that perceives its environment and executes actions. It represents the learning algorithm itself, such as a neural network or a Q-table. In an agricultural context, this could be a sophisticated livestock monitoring algorithm.

Environment constitutes the external system with which the agent interacts. It defines the rules of engagement and responds to the agent's actions by transitioning to a new state and providing a reward signal. For a livestock monitoring system, the environment is the physical space of the barn and the physiological state of the animals within it.

State is a complete description of the environment at a specific moment in time. It provides the agent with all the necessary information to make a decision. In the context of estrus detection, the state could be a vector of numerical sensor readings, such as movement activity, body temperature, and mounting frequency.
Actions are the set of all possible decisions or moves that the agent can perform from a given state. These actions directly influence the environment, causing it to change. Examples include sending a veterinarian alert, signaling for insemination, or taking no action.
Reward is a scalar feedback signal provided by the environment to the agent after each action. It represents the immediate desirability of a state-action pair. The reward is the primary mechanism through which the agent learns what constitutes "good" or "bad" behavior. For instance, a positive reward (+1) might be granted for a successful estrus detection, while a negative reward (-1) is given for a missed detection or a false alarm.
Policy is the agent's strategy. It is a mapping from observed states to actions, which dictates the agent's behavior. The central goal of an RL algorithm is to discover the optimal policy that maximizes the expected total reward over the long run.

RL encompasses a diverse array of algorithms, broadly categorized according to their foundational principles. A general distinction exists between Bandit-based methods and those grounded in Markov Decision Processes (MDPs). Bandit algorithms, such as Multi-Armed Bandits, address single-state decision problems where the objective is to select the action that maximizes immediate reward. MDPs are usually effective in static environments but inherently lack the capacity to model temporal dependencies or long-term consequences of actions, rendering them unsuitable for sequential decision-making tasks. In contrast, MDP-based algorithms are designed to handle dynamic environments where the state evolves over time in response to the agent's actions. These algorithms incorporate the notion of delayed rewards and optimize policies based on cumulative future returns. Prominent examples include:

Policy Gradient methods (e.g., REINFORCE), which directly parameterize and optimize the policy,
Actor-Critic methods, which integrate policy optimization with value function estimation,
Value-based methods (e.g., Q-Learning), which learn a value function to guide action selection.
In this section, an RL implementation is desribed to detect estrus in dairy cows, contrasting with the traditional machine learning example previously shown with RF. Q-learning (QL) is demonstrated as a representative and widely adopted value-based RL algorithm. Its simplicity, robustness, and effectiveness in environments with discrete state and action spaces make it particularly well-suited to our application. QL estimates the expected cumulative reward of taking a given action in a specific state via a learned action-value function (Q-function). As a model-free algorithm, it does not require prior knowledge of the environment's dynamics, enabling the agent to derive an optimal policy through direct interaction with the environment. These characteristics make QL a practical and reliable choice for our estrus detection system.

The example application is based on a simplified QL-based RL code with R libraries, as presented in Supplementary Code 2. In the code, an AI agent operating with the QL algorithm learns to make optimal decisions through a process of trial and error. The agent bases its decisions on three key physiological and behavioral variables collected from a cow: movement, body temperature, and mount count. The model's objective is to learn which actions (sending an estrus alert or taking no action) yield the highest reward for specific combinations of these variables. This approach allows the system to improve over time, enabling the most accurate estrus detection from complex and dynamic data.

The EstrusEnvironment class serves as the core of the reinforcement learning framework, encapsulating both the structure of the environment and the logic of the QL algorithm. Within this class, the physiological state of a cow (defined by movement, body temperature, and mount count) is first normalized and discretized into a finite number of bins. This transformation enables the agent to operate within a manageable, discrete state space, which is essential for tabular QL.

The agent is tasked with choosing between two actions: issuing an estrus alert or taking no action. These decisions are guided by a four-dimensional Q-table, which stores the estimated value of each action for every possible state combination. During training, the agent interacts with time-series data from individual cows, updating its Q-values based on the rewards received. This learning process is governed by an epsilon greedy (ε-greedy) exploration strategy, where the agent occasionally selects random actions to explore the environment, gradually shifting toward exploitation as epsilon decays over time.

A central component of the RL code is the reward function, which is designed to reflect the practical consequences of the agent's decisions. If the agent correctly identifies an estrus event and sends an alert, it receives a positive reward. Conversely, false alerts or missed detections incur penalties. For example, sending an alert when the cow is not in estrus results in a negative reward, while correctly choosing not to act when no estrus is present yields a small positive reinforcement. This reward structure incentivizes the agent to maximize true positives while minimizing false positives and false negatives, aligning its learning objective with the real-world goals of estrus detection.

To train and evaluate the agent, a synthetic dataset is generated that simulates realistic estrus behavior across a population of 200 cows over a 48-hour period. The physiological signals (movement, temperature, and mount count) are modeled using statistical distributions that vary according to estrus type, including normal, silent, and false estrus. Each time point is labeled with a binary estrus flag, allowing the agent to learn from both typical and atypical patterns of behavior. Training is conducted over 50 episodes, during which the agent refines its policy by interacting with the simulated environment. Performance metrics such as cumulative reward and prediction accuracy are tracked and visualized to monitor learning progress. In the code, the reward function is defined within the get_reward method of the EstrusEnvironment R6 class. It is a simple, rule-based system that assigns a numerical value (a reward or penalty) to the agent's action based on whether it correctly identified the cow's estrus status. The reward function, *R(a,true_estrus)*, can be formulated as follows:

If the agent's action (a) is to "send_alert":

If the cow is actually in estrus (true_estrus == "Yes"), the agent receives a positive reward of +5. This is a significant reward for a correct and valuable action.

If the cow is not in estrus (true_estrus == "No"), the agent receives a penalty of -3. This is a moderate penalty for a false positive, which can lead to unnecessary labor.

If the agent's action (a) is to "no_action":

If the cow is actually not in estrus (true_estrus == "No"), the agent receives a positive reward of +1. This is a small reward for correctly ignoring a normal state, reinforcing efficient behavior.

If the cow is actually in estrus (true_estrus == "Yes"), the agent receives a significant penalty of -5. This is the highest penalty, designed to strongly discourage missed estrus periods, as this is a costly mistake in a farm setting.

The actions in the provided R code for the Q-learning agent are defined as a vector of two possible choices: "send_alert" and "no_action". The agent's goal is to learn which of these two actions is optimal for a given state, in order to maximize its cumulative reward over time.

Once trained, the agent is evaluated on a separate test set, where its predicted actions are mapped to estrus classifications. These predictions are then compared to ground truth labels to assess the model's diagnostic accuracy. Figure 6 shows the training performance of the RL model over just 50 episodes in two sub-panels, representing two key performance metrics such as cumulative reward and prediction accuracy. In the top panel, indicates that the QL agent is effectively learning to make more optimal decisions, resulting in a higher total reward over time. The consistent increase in reward suggests that the agent is successfully navigating the trade-off between positive and negative rewards defined by the reward function. Similarly, in the bottom panel, a positive trend in the model's prediction accuracy is seen. The accuracy shows gradual improvement, rising from an initial value of approximately 86% to nearly 89% by the end of the training.

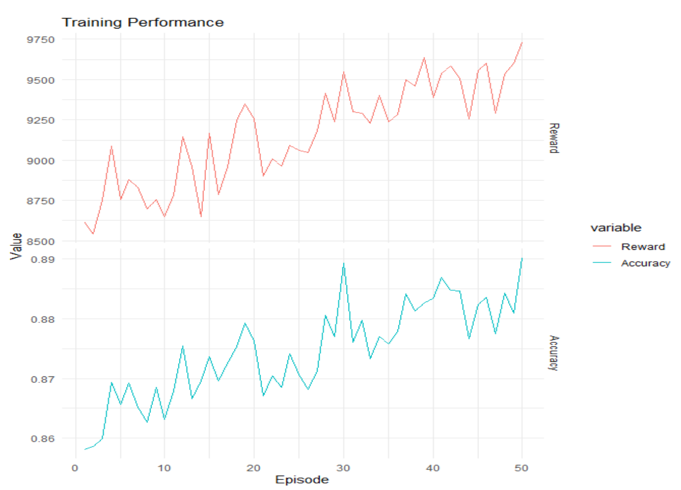


Figure 6. Training performance by the episodes

The Q-learning model demonstrated strong diagnostic capability on the test set, achieving high accuracy (96.14%), sensitivity (89.91%), specificity (97.98%), precision (92.89%), and an F1-score (91.38%). This balanced performance across all key metrics is particularly significant for practical estrus detection. The high sensitivity ensures the model effectively captures the majority of true estrus events, minimizing missed opportunities for insemination which directly impact farm productivity. Concurrently, the exceptional specificity and precision indicate a low rate of false alarms, reducing unnecessary labor, animal stress, and resource expenditure associated with investigating non-estrus cases. The high F1-score confirms the model successfully harmonizes these competing objectives – detecting true positives while maintaining alert reliability. This balanced outcome is a direct result of the reward structure designed to penalize both false negatives and false positives during training. Collectively, these results validate the Q-learning agent's ability to learn a robust, generalizable policy for automated estrus detection, highlighting its potential as a reliable and practical tool for enhancing reproductive management in precision livestock farming.

Conclusions

The evaluation RL with the Q-learning model on the test dataset demonstrates its strong capability in accurately detecting estrus events in dairy cows. This model achieved an overall classification accuracy of 96.14%, indicating that it correctly identified both estrus and non-estrus states in the majority of cases. This high accuracy reflects the agent's effective learning of the underlying decision policy. Sensitivity (or recall) was measured at 89.91%, suggesting that the model successfully detected nearly 90% of all true estrus events. This is particularly important in practical applications, where missed detections can lead to lost reproductive opportunities and economic inefficiencies. The model also exhibited a specificity of 97.98%, confirming its robustness in correctly identifying non-estrus cases and minimizing false positives. Such precision is essential for reducing unnecessary interventions and optimizing farm labor. The precision score reached 92.89%, indicating that when the model issued an estrus alert, it was correct in over 92% of instances. This high precision ensures that alerts are both reliable and actionable, enhancing trust in the system's recommendations. The F1-score, which balances precision and recall, was calculated at 91.38%, further validating the model's diagnostic consistency and its ability to manage the trade-off between sensitivity and specificity. Collectively, these metrics confirm that the Q-learning agent has effectively learned to distinguish between estrus and non-estrus states based on physiological and behavioral inputs. The model's performance across all key indicators supports its potential deployment as a reliable and autonomous agent for estrus detection in precision livestock farming.

On a simulate dataset, this study demonstrated the effectiveness of both RL and traditional ML models for automated estrus detection in precision livestock farming. The findings validate two distinct but promising machine learning models to this critical task. The Q-learning model achieved a balanced performance, with a 96.14% accuracy, 89.91% sensitivity, and 97.98% specificity, showing its ability to learn optimal decision-making policies through trial-and-error interactions. In contrast, the RF model exhibited a slightly higher overall accuracy of 96.51% but prioritized the correct classification of non-estrus cases, leading to a high specificity of 99.06% for the 'No' class at the expense of a lower sensitivity of 87.84% for true estrus events. The key distinction between the two learning type lies in their inherent learning objectives. The Q-learning model's reward structure enabled a more balanced performance, making it a promising tool for both minimizing false alarms and ensuring that estrus events are not missed. Conversely, the RF model, by optimizing for overall accuracy, proved to be more conservative in its estrus predictions. This suggests that the choice between approaches should depend on specific farming objectives whether prioritizing the detection of all estrus events or minimizing false alarms.

As a conclusion, the RL-based and RF-based agents demonstrate the feasibility of using machine learning for estrus detection. Their modular design, interpretable decision logic, and adaptability to real-world deployment make them strong starting points for precision livestock monitoring systems. With further enhancements in temporal modeling, action space design, and real-world validation, this approach can support more efficient, sustainable, and welfare-conscious reproductive management in modern agriculture. Future improvements could significantly enhance system accuracy and scalability. Integrating additional data types such as detailed GPS movement patterns and sound spectrum analysis would provide a more complete behavioral profile. Advanced time-series analysis using models like ARIMA could refine detection of estrus cycles. A farmer-friendly dashboard built using R Shiny could make the system more interactive and accessible. Shifting computations to edge devices such as Raspberry Pi would allow for real-time, offline processing in remote areas. RL could be incorporated to allow the system to improve its performance continuously based on outcomes and feedback.

Although this study focused solely on learning models, the agent can be easily enhanced with functions to acquire real-time sensor data via an API, save it to a database, and periodically retrain the model with new data to improve performance and keep the agent's Q-table up-to-date. These processes can be automated on a server or in a cloud environment using a cron job or scheduled task. This allows the model to be automatically retrained and optimized with the latest sensor data. Additionally, real-time data from the cows can be fed to the model at regular intervals, and the results can be sent to the farmer via SMS or other means. This requires using an SMS gateway service's API. For example, in R, the prediction results can be sent with a very simple function via the httr library, which provides a connection to third-party services like Twilio or Vonage for sending SMS messages over the internet. Furthermore, deeper integration and interaction with farm automation tools via LLMs could enable immediate follow-up actions such as notifying veterinarians or adjusting reproductive plans.

Acknowledgements

I would like to express my sincere gratitude to Congress President Prof. Dr. Ahmet Şekeroğlu for inviting me to present this paper at the conference, and to the organizing committee for their excellent hospitality.

References

Andersson, L. M., Okada, H., Miura, R., Zhang, Y., Yoshioka, K., Aso, H., & Itoh, T. (2016). Wearable wireless estrus detection sensor for cows. Computers and Electronics in Agriculture, 127, 101-108.

At-Taras, E. E., & Spahr, S. L. (2001). Detection and characterization of estrus in dairy cattle with an electronic heatmount detector and an electronic activity tag. Journal of Dairy Science, 84(4), 792-798.

Bharali, D., K.C. Deka, B.C. Deka, K.C. Nath, R.K. Biswas, L.J. Dutta and Sarmah, B.K. (2019). Incidence of Silent Oestrus and an Investigation of Reproductive Status in Crossbred Cows under Field Conditions of Assam.Int.J.Curr.Microbiol.App.Sci. 8(5), 1922-1925. doi: https://doi.org/10.20546/ijcmas.2019.805.222

Delwiche, M., Tang, X., BonDurant, R., & Munro, C. (2001). Estrus detection with a progesterone biosensor. Transactions of the ASAE, 44(6), 2003.

Kennedy, A. D., & Ingalls, J. R. (1995). Estrus detection with activity tags in dairy cows housed in tie-stalls. Canadian Journal of Animal Science, 75(4), 633-636.

Kim, J. Y., Lee, J. S., Jo, Y. H., & Lee, H. G. (2023). Measuring the effects of estrus on rumen temperature and environment, behavior and physiological attributes in Korean Native breeding cattle. Journal of Animal Science and Technology, 65(3), 579.

Lodkaew, T., Pasupa, K., & Loo, C. K. (2023). CowXNet: An automated cow estrus detection system. Expert Systems with Applications, 211, 118550.

Luo, R. C., Yih, C. C., & Su, K. L. (2002). Multisensor fusion and integration: approaches, applications, and future research directions. IEEE Sensors Journal, 2(2), 107-119.

Merkelytė, I., Šiukščius, A., & Nainienė, R. (2025). The Role of Sensor Technologies in Estrus Detection in Beef Cattle: A Review of Current Applications. Animals, 15(15), 2313

Mičiaková, M., Strapák, P., Szencziová, I., & Strapáková, E. (2018). Several methods of estrus detection in cattle dams: a review. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 66(2).

Mičiaková, M., Strapák, P., & Strapáková, E. (2024). The influence of selected factors on changes in locomotion activity during estrus in dairy cows. Animals, 14(10), 1421.

Obeidat, M. A., Abdallah, J., Hamadneh, T., Qawaqneh, H., & Mansour, A. M. (2024). Enhancing Agricultural Operations Through AI-Driven Agent Communication in Smart Farming Systems. Ingenierie des Systemes d'Information, 29(3), 917.

R Core Team (2025). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Redden, K. D., Kennedy, A. D., Ingalls, J. R., & Gilson, T. L. (1993). Detection of estrus by radiotelemetric monitoring of vaginal and ear skin temperature and pedometer measurements of activity. Journal of dairy science, 76(3), 713-721.

Reith, S., & Hoy, S. (2018). Behavioral signs of estrus and the potential of fully automated systems for detection of estrus in dairy cattle. Animal, 12(2), 398-407.

Roelofs, J. B., van Eerdenburg, F. J., Soede, N. M., & Kemp, B. (2005). Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. Theriogenology, 64(8), 1690-1703.

Roelofs, J. B., & Van Erp-van der Kooij, E. (2018). Estrus detection tools and their applicability in cattle: recent and perspectival situation. Animal Reproduction, 12(3), 498-504.

Rorie, R. W., Bilby, T. R., & Lester, T. D. (2002). Application of electronic estrus detection technologies to reproductive management of cattle. Theriogenology, 57(1), 137-148.

Rudowsky, I. (2004). Intelligent agents. Communications of the Association for Information Systems, 14(1), https://doi.org/10.17705/1CAIS.01414

Santos, C. A. D., Landim, N. M. D., Araújo, H. X. D., & Paim, T. D. P. (2022). Automated systems for estrous and calving detection in dairy cattle. AgriEngineering, 4(2), 475-482

Sharifuzzaman, M., Mun, H. S., Ampode, K. M. B., Lagua, E. B., Park, H. R., Kim, Y. H., ... & Yang, C. J. (2024). Technological tools and artificial intelligence in estrus detection of sows—a comprehensive review. Animals, 14(3), 471.

Stevenson, J. S. (2021). Daily activity measures and milk yield immediately before and after a fertile estrus and during the period of expected return to estrus after insemination in dairy cows. Journal of Dairy Science, 104(10), 11277-11290.

Suthar, V. S., Burfeind, O., Patel, J. S., Dhami, A. J., & Heuwieser, W. (2011). Body temperature around induced estrus in dairy cows. Journal of dairy science, 94(5), 2368-2373.

Talukder, S., Kerrisk, K. L., Ingenhoff, L., Thomson, P. C., Garcia, S. C., & Celi, P. (2014). Infrared technology for estrus detection and as a predictor of time of ovulation in dairy cows in a pasture-based system. Theriogenology, 81(7), 925-935.

Wang, J., Bell, M., Liu, X., & Liu, G. (2020). Machine-learning techniques can enhance dairy cow estrus detection using location and acceleration data. Animals, 10(7), 1160.

Wang, S., Zhang, H., Tian, H., Chen, X., Li, S., Lu, Y., ... & Wang, D. (2020). Alterations in vaginal temperature during the estrous cycle in dairy cows detected by a new intravaginal device—a pilot study. Tropical animal health and production, 52(5), 2265-2271.

Wang, R., Gao, Z., Li, Q., Zhao, C., Gao, R., Zhang, H., ... & Feng, L. (2022). Detection method of cow estrus behavior in natural scenes based on improved YOLOv5. Agriculture, 12(9), 1339.

Wooldridge, M., & Jennings, N. R. (1995). Intelligent agents: Theory and practice. The knowledge engineering review, 10(2), 115-152.

Yaseen, M. (2024). What is YOLOv9: An in-depth exploration of the internal features of the next-generation object detector. arXiv preprint arXiv:2409.07813.

Yin, L., Hong, T., & Liu, C. (2013). Estrus Detection in Dairy Cows from Acceleration Data using Self-learning Classification Models. J. Comput., 8(10), 2590-2597.

Zdunczyk, S., Piskula, M., Janowski, T. O. M. A. S. Z., Baranski, W., & Ras, M. (2005). Concentrations of isoflavones in blood plasma of dairy cows with different incidence of silent heat. Bull. Vet. Inst. Pulawy, 49, 189-191.

Supplementary Materials

Supplementary Code 1

```
# A Simple RF ML model for Estrus Detection Agent in R
# Load the require libraries
library(randomForest)
library(caret)
library(pROC)
library(ggplot2)
library(reshape2)
library(patchwork)

set.seed(123)
# Estrus data simulation
# Set simulation parameters
n_cows <- 200
n_hours <- 48

# Normal activity and temperature
baseline_movement <- 100      # AU/h
```

```
baseline_temp <- 38.5        # °C

# Estrus conditions
estrus_multiplier <- 2.0      # movement increase
estrus_temp_increase <- 0.4   # temperature increase
lambda_no <- 0.2              # mounts absent
lambda_yes <- 3               # mounts present
estrus_duration <- 12

# Estrus types
estrus_types <- c("normal", "silent", "false")
p_silent <- 0.15   # 15% silent estrus
p_false <- 0.10    # 10% false estrus

# Assign estrus type for each cow
estrus_type_vec <- sample(
  estrus_types,
  n_cows,
  replace = TRUE,
  prob = c(1 - p_silent - p_false, p_silent, p_false)
)

# Simulate data for cows
data_estrus <- data.frame()

for (cow in 1:n_cows) {
  estrus_start_cow <- sample(20:28, 1)
  time <- 1:n_hours
  estrus_type <- estrus_type_vec[cow]

  movement <- sapply(time, function(t) {
    if (estrus_type == "normal" &&
      t >= estrus_start_cow & t < estrus_start_cow + estrus_duration) {
        rnorm(1, baseline_movement * estrus_multiplier, 15)
    } else {
        rnorm(1, baseline_movement, 10)
    }
  })

  temperature <- sapply(time, function(t) {
    if (estrus_type == "normal" &&
      t >= estrus_start_cow & t < estrus_start_cow + estrus_duration) {
       rnorm(1, baseline_temp + estrus_temp_increase, 0.1)
    } else if (estrus_type == "silent" &&
       t >= estrus_start_cow & t < estrus_start_cow + estrus_duration) {
        rnorm(1, baseline_temp + 0.2, 0.1)  # sessiz estrus hafif artış
    } else {
        rnorm(1, baseline_temp, 0.1)
    }
  })

  mount_count <- sapply(time, function(t) {
    base <- if (t >= estrus_start_cow & t < estrus_start_cow + estrus_duration) {
      if (estrus_type == "normal") lambda_yes else if (estrus_type == "silent") lambda_no
      else if (estrus_type == "false") lambda_no + 3
    } else {
      lambda_no
    }
      rpois(1, base)
  })
```

```
  estrus_flag <- sapply(time, function(t) {
    if (t >= estrus_start_cow & t < estrus_start_cow + estrus_duration &
      estrus_type != "false") "Yes" else "No"
  })

  data_cow <- data.frame(
    cow_id = cow,
    time = time,
    movement = movement,
    temperature = temperature,
    mount_count = mount_count,
    estrus = factor(estrus_flag),
    estrus_type = estrus_type
  )

  data_estrus <- rbind(data_estrus, data_cow)
}

# Function to plot timeseries with estrus
plot_cow_timeseries <- function(data, cow_number) {
  cow_data <- subset(data, cow_id == cow_number)

  p1 <- ggplot(cow_data, aes(x = time, y = movement, group = 1)) +
    geom_line(aes(color = estrus), size = 1) +
    labs(title = paste("Cow", cow_number, "- Movement"),
         x = "Time (h)", y = "Movement (AU/h)") +
    scale_color_manual(values = c("No" = "blue", "Yes" = "red")) +
    theme_minimal()

  p2 <- ggplot(cow_data, aes(x = time, y = temperature, group = 1)) +
    geom_line(aes(color = estrus), size = 1) +
    labs(title = paste("Cow", cow_number, "- Temperature"),
         x = "Time (h)", y = "Temperature (°C)") +
    scale_color_manual(values = c("No" = "blue", "Yes" = "red")) +
    theme_minimal()

  p3 <- ggplot(cow_data, aes(x = time, y = mount_count, group = 1)) +
    geom_line(aes(color = estrus), size = 1) +
    labs(title = paste("Cow", cow_number, "- Mount Number"),
         x = "Time (h)", y = "Mounts (count)") +
    scale_color_manual(values = c("No" = "blue", "Yes" = "red")) +
    theme_minimal()

  (p1 / p2 / p3) + plot_layout(guides = "collect")
}

# Example plot for cow 42
plot_cow_timeseries(data_estrus, 42)

# Splitting train/test data
train_index <- createDataPartition(data_estrus$estrus, p = 0.8, list = FALSE)
train_data <- data_estrus[train_index, ]
test_data <- data_estrus[-train_index, ]

# Apply Random Forest Model
rf_model <- randomForest(
  estrus ~ movement + temperature + mount_count,
  data = train_data,
  ntree = 200,
```

```
  importance = TRUE
)
print(rf_model)

# Variable importance
var_importance <- varImpPlot(rf_model, main = "Variable Importance")
print(var_importance)

# Testing and evaluating model
predictions <- predict(rf_model, test_data)
cm <- confusionMatrix(predictions, test_data$estrus)
print(cm)

# Confusion Matrix Heatmap
cm_table <- as.data.frame(cm$table)
cm_table$Prediction <- factor(cm_table$Prediction, levels = c("Yes", "No"))
cm_table$Reference  <- factor(cm_table$Reference,  levels = c("Yes", "No"))

p_cm <- ggplot(cm_table, aes(x = Reference, y = Prediction, fill = Freq)) +
  geom_tile(color = "white") +
  geom_text(aes(label = Freq), vjust = 1, size = 6) +
  scale_fill_gradient(low = "lightblue", high = "red") +
  labs(title = "Confusion Matrix Heatmap (Test Set)",
       x = "Actual Estrus",
       y = "Predicted Estrus",
       fill = "Count") +
  theme_minimal(base_size = 14)

# ROC Curve
pred_probs <- predict(rf_model, test_data, type = "prob")[, "Yes"]
roc_obj <- roc(response = test_data$estrus, predictor = pred_probs, levels = c("No", "Yes"))

p_roc <- ggroc(roc_obj, color = "darkblue", size = 1.2) +
  geom_abline(slope = 1, intercept = 0, linetype = "dashed", color = "gray50") +
  labs(title = paste0("ROC Curve (AUROC = ", round(auc(roc_obj), 3), ")"),
       x = "False Positive Rate",
       y = "True Positive Rate") +
  theme_minimal(base_size = 14)

p_cm | p_roc   # side by side panel

# Visualization for false-estrus using mounting and movement
plot_false_estrus <- function(data, dataset_name) {
  ggplot(data, aes(x = mount_count, y = movement)) +
    geom_point(aes(color = estrus, shape = estrus_type), alpha = 0.7, size = 3) +
    scale_color_manual(values = c("No" = "blue", "Yes" = "red")) +
    scale_shape_manual(values = c("normal" = 16, "silent" = 17, "false" = 15)) +
    labs(title = paste(dataset_name, ": Estrus Types"),
         x = "Mount Number", y = "Movement (AU/h)",
         color = "Actual Estrus", shape = "Estrus Type") +
    theme_minimal()
}

p_train <- plot_false_estrus(train_data, "Training Set")
p_test <- plot_false_estrus(test_data, "Test Set")
p_train / p_test  # with patchwork
```

Supplementary Code 2

```
# A Simple Q-learning RL for Estrus Detection Agent in R
# Load the require libraries
```

```
library(R6)
library(dplyr)
library(ggplot2)
library(reshape2)
library(caret)

nepisodes <- 50 # Number of episodes

# Define EstrusEnvironment R6 Class
# for Reinforcement Learning environment for estrus detection
EstrusEnvironment <- R6::R6Class(
  "EstrusEnvironment",
  public = list(
    # Parameters for the Q-learning model
    movement_bins = 10, temp_bins = 10, mounts_bins = 5,
    actions = c("send_alert", "no_action"),
    learning_rate = 0.1, discount_factor = 0.95,
    epsilon = 0.2, min_epsilon = 0.01, epsilon_decay = 0.995,

    # Initialize the class with the training data
    initialize = function(data) {
      private$data <- data
      private$initialize_q_table()
      private$data_range <- private$get_data_ranges()
    },

    # Predict the best action for a given state
    predict = function(movement, temperature, mount_count) {
      state_norm <- private$normalize_state(c(movement, temperature, mount_count))
      state_idx <- private$discretize_state(state_norm)
      action_idx <- which.max(private$q_table[state_idx[1], state_idx[2], state_idx[3], ])
      return(self$actions[action_idx])
    },

    # Train the Q-learning model

    train = function(episodes = nepisodes) {
      reward_history <- numeric(episodes)
      accuracy_history <- numeric(episodes)

      for (episode in 1:episodes) {
        shuffled_cows <- sample(unique(private$data$cow_id))
        total_reward <- 0
        correct_predictions <- 0
        total_predictions <- 0

        for (cow in shuffled_cows) {
          cow_data <- private$data %>% filter(cow_id == cow)
          for (i in 1:(nrow(cow_data) - 1)) {
            state <- cow_data[i, c("movement", "temperature", "mount_count")]
            true_estrus <- cow_data[i, "estrus"]

            action <- private$choose_action(as.numeric(state))
            next_state_obs <- cow_data[i + 1, c("movement", "temperature", "mount_count")]
            reward <- private$get_reward(action, true_estrus)

            total_reward <- total_reward + reward
            total_predictions <- total_predictions + 1
            if ((action == "send_alert" & true_estrus == "Yes") | (
            action == "no_action" & true_estrus == "No")) {
```

```
          correct_predictions <- correct_predictions + 1
        }
        private$update_q_table(as.numeric(state), action, reward, as.numeric(next_state_obs))
      }
    }

    self$epsilon <- max(self$min_epsilon, self$epsilon * self$epsilon_decay)
    reward_history[episode] <- total_reward
    accuracy_history[episode] <- correct_predictions / total_predictions

    if (episode %% 10 == 0) {
      message(sprintf("Episode %d: Reward=%.1f, Accuracy=%.1f%%, ε=%.3f",
        episode, total_reward, accuracy_history[episode]*100, self$epsilon))
    }
  }
  private$plot_results(reward_history, accuracy_history)
 }
),

private = list(
 data = NULL,
 data_range = NULL,
 q_table = NULL,

 initialize_q_table = function() {
  private$q_table <- array(
    0, dim = c(self$movement_bins, self$temp_bins, self$mounts_bins, length(self$actions))
  )
 },

 get_data_ranges = function() {
  list(
    movement = range(private$data$movement),
    temperature = range(private$data$temperature),
    mounts = range(private$data$mount_count)
  )
 },

 normalize_state = function(s) {
  (s - c(private$data_range$movement[1], private$data_range$temperature[1],
  private$data_range$mounts[1])) /  (c(private$data_range$movement[2],
  private$data_range$temperature[2], private$data_range$mounts[2]) –
  c(private$data_range$movement[1], private$data_range$temperature[1],
  private$data_range$mounts[1]))
 },

 discretize_state = function(s_norm) {
  pmin(
    pmax(
      c(
        floor(s_norm[1] * self$movement_bins) + 1,
        floor(s_norm[2] * self$temp_bins) + 1,
        floor(s_norm[3] * self$mounts_bins) + 1
      ), 1),
    c(self$movement_bins, self$temp_bins, self$mounts_bins)
  )
 },

 get_reward = function(a, true) {
  if (a == "send_alert") {
```

```
      return(ifelse(true == "Yes", 5, -3))
    } else if (a == "no_action") {
      return(ifelse(true == "No", 1, -5))
    } else {
      return(0)
    }
  },

  choose_action = function(s) {
    s_norm <- private$normalize_state(s)
    s_idx <- private$discretize_state(s_norm)

    if (runif(1) < self$epsilon) {
      return(sample(self$actions, 1))
    }

    return(self$actions[which.max(private$q_table[s_idx[1], s_idx[2], s_idx[3], ])])
  },

  update_q_table = function(s, a, r, s_next) {
    s_idx <- private$discretize_state(private$normalize_state(s))
    s_next_idx <- private$discretize_state(private$normalize_state(s_next))
    a_idx <- which(self$actions == a)

    old_q_value <- private$q_table[s_idx[1], s_idx[2], s_idx[3], a_idx]
    max_next_q <- max(private$q_table[s_next_idx[1], s_next_idx[2], s_next_idx[3], ])

    new_q_value <- old_q_value + self$learning_rate * (r + self$discount_factor * max_next_q - old_q_value)
    private$q_table[s_idx[1], s_idx[2], s_idx[3], a_idx] <- new_q_value
  },

  plot_results = function(rewards, accuracy) {
    df <- data.frame(
      Episode = seq_along(rewards),
      Reward = rewards,
      Accuracy = accuracy
    )
    ggplot(melt(df, "Episode"), aes(Episode, value, color=variable)) +
      geom_line() + facet_grid(variable~., scales="free_y") +
      labs(title="Training Performance", y="Value") + theme_minimal()
  }
 )
)

# Data Simulation
# Simulation parameters
set.seed(123)
n_cows <- 200
n_hours <- 48
baseline_movement <- 100
baseline_temp <- 38.5
estrus_multiplier <- 2.0
estrus_temp_increase <- 0.4
lambda_no <- 0.2
lambda_yes <- 3
estrus_duration <- 12
estrus_types <- c("normal", "silent", "false")
p_silent <- 0.15
p_false <- 0.10
```

```
estrus_type_vec <- sample(estrus_types, n_cows, replace = TRUE,
 prob = c(1 - p_silent - p_false, p_silent, p_false))

data_estrus <- data.frame()
for (cow in 1:n_cows) {
  estrus_start_cow <- sample(20:28, 1)
  time <- 1:n_hours
  estrus_type <- estrus_type_vec[cow]

  movement <- sapply(time, function(t) {
    if (estrus_type == "normal" && t >= estrus_start_cow & t < estrus_start_cow + estrus_duration) {
      rnorm(1, baseline_movement * estrus_multiplier, 15)
    } else {
      rnorm(1, baseline_movement, 10)
    }
  })

  temperature <- sapply(time, function(t) {
    if (estrus_type == "normal" && t >= estrus_start_cow & t < estrus_start_cow + estrus_duration) {
      rnorm(1, baseline_temp + estrus_temp_increase, 0.1)
    } else if (estrus_type == "silent" && t >= estrus_start_cow & t < estrus_start_cow + estrus_duration) {
      rnorm(1, baseline_temp + 0.2, 0.1)
    } else {
      rnorm(1, baseline_temp, 0.1)
    }
  })

  mount_count <- sapply(time, function(t) {
    base <- if (t >= estrus_start_cow & t < estrus_start_cow + estrus_duration) {
      if (estrus_type == "normal") lambda_yes else if (estrus_type == "silent") lambda_no
      else if (estrus_type == "false") lambda_yes
    } else {
      lambda_no
    }
    rpois(1, base)
  })

  estrus_flag <- sapply(time, function(t) {
    if (t >= estrus_start_cow & t < estrus_start_cow + estrus_duration & estrus_type != "false") "Yes"
     else "No"})

  data_cow <- data.frame(
    cow_id = cow,
    time = time,
    movement = movement,
    temperature = temperature,
    mount_count = mount_count,
    estrus = factor(estrus_flag),
    estrus_type = estrus_type
  )
  data_estrus <- rbind(data_estrus, data_cow)
}

# Model Training and Evaluation
# Split data into training and test sets
train_index <- createDataPartition(data_estrus$estrus, p = 0.8, list = FALSE)
train_data_estrus <- data_estrus[train_index, ]
test_data_estrus <- data_estrus[-train_index, ]

# Train the model with the training data
```

```
env <- EstrusEnvironment$new(data = train_data_estrus)
env$train(episodes = 50)

# Performance Evaluation on the Test Set
# Get model predictions for the test set
predictions <- test_data_estrus %>%
  rowwise() %>%
  mutate(predicted_action = env$predict(movement, temperature, mount_count)) %>%
  ungroup() %>%
  mutate(predicted_estrus = ifelse(predicted_action == "send_alert", "Yes", "No"))

# Align factor levels for the confusion matrix
predictions$predicted_estrus <- factor(predictions$predicted_estrus, levels =
 levels(test_data_estrus$estrus))
test_data_estrus$estrus <- factor(test_data_estrus$estrus, levels = c("Yes", "No"))

# Calculate and print the Confusion Matrix and performance metrics
cat("\n\n Confusion Matrix and Performance Metrics \n")
cm <- confusionMatrix(predictions$predicted_estrus, test_data_estrus$estrus, positive = "Yes")
print(cm)

# Display a summary of key metrics
cat("\n\n Performance Metrics Summary \n")
metrics <- cm$byClass
F1_Score <- 2 * (metrics['Pos Pred Value'] * metrics['Sensitivity']) / (metrics['Pos Pred Value'] +
metrics['Sensitivity'])
Accuracy <- cm$overall['Accuracy']

cat(sprintf("Accuracy: %.4f\n", Accuracy))
cat(sprintf("Sensitivity (Recall): %.4f\n", metrics['Sensitivity']))
cat(sprintf("Specificity: %.4f\n", metrics['Specificity']))
cat(sprintf("Precision (Pos Pred Value): %.4f\n", metrics['Pos Pred Value']))
cat(sprintf("F1-Score: %.4f\n", F1_Score))

# Message codes for a subset of test cases
# A small set of test cases for 4 cows
test_cases <- data.frame(
  movement = c(150, 220, 95, 110),
  temperature = c(38.8, 39.3, 38.4, 38.6),
  mount_count = c(2, 5, 0, 1)
)

cat("\n\n Alert Message\n")
for(i in 1:nrow(test_cases)) {
  pred <- env$predict(test_cases$movement[i], test_cases$temperature[i], test_cases$mount_count[i])
  if (pred == "send_alert") {
    cat(sprintf("ALERT! Cow's vitals (Move: %.1f, Temp: %.1f, Mounts: %.1f) indicate a high prob of estrus.\n",
        test_cases$movement[i], test_cases$temperature[i], test_cases$mount_count[i]))
  } else {
    cat(sprintf("Normal activity for cow vitals (Move: %.1f, Temp: %.1f, Mounts: %.1f). No action required.\n",
       test_cases$movement[i], test_cases$temperature[i], test_cases$mount_count[i]))
  }
}
```

The Effects Of Defıcıt Irrıgatıon On The Yıeld Parameters Of Some Strawberry Varıetıes In Nıgde Condıtıons

Burak Şen[1], Berna Gümüş[2]

[1] Department of Biyosystem Engineering, Faculty of Agricultural Sciences and Technologies, Nigde Ömer Halisdemir University, Niğde, Türkiye
[2] Department of Plant Production and Technologies, Graduate School Of Natural and Applied Sciences, Nigde Ömer Halisdemir University, Niğde, Türkiye

Abstract

This study was conducted on three different strawberry varieties grown under Niğde's climatic conditions, where Turkey ranks fourth globally in terms of production volume. The experiment aimed to investigate the effects of different irrigation levels on yield and to determine the most suitable strawberry variety for the region. Irrigation treatments were applied to the strawberry varieties based on open surface evaporation, with I100 representing full irrigation, and I75 and I50 representing deficit irrigation. The experiment was carried out over two years, in 2021 and 2022. The yield per plant, number of fruits, average fruit size, and yield per decare were calculated for each treatment. In the first year, the Monterey strawberry variety was observed to have a higher yield compared to Albion and San Andreas varieties. In the second year, the Albion variety showed a higher yield than the other varieties. The highest yield was achieved with full irrigation.
Key Words: *Strawberry Varieties, Restricted Irrigation, Niğde, Albion, San Andreas*

Niğde Koşullarinda Kisintili Sulamanin Bazi Çilek Çeşitlerinde Verim Parametrelerine Etkileri

Özet

Bu çalışma Türkiye'nin üretim miktarında küresel ölçekte dördüncü sırada yer aldığı çilekte Niğde iklim koşullarında yetiştirilen 3 farklı çilek çeşidinde yapılmıştır. Deneme farklı sulama düzeyinin verim üzerine etkilerinin araştırılması ve bölgeye en uygun çilek çeşidinin belirlenmesi amacıyla gerçekleştirilmiştir. Çilek çeşitlerine açık yüzey buharlaşması dikkate alınarak I100 tam sulama konusu ile I75 ve I50 kısıntılı sulama konuları uygulanmıştır. Deneme 2021 ve 2022 yıllarında 2 yıl olarak yürütülmüştür. Uygulanan konuda bitki başına verim, meyve sayısı ve ortalama meyve büyüklüğü ile dekara verim miktarları hesaplanmıştır. İlk yılda Monterey çilek çeşidinin Albion ve San Andreas çeşitlerine göre verimi daha yüksek olduğu gözlemlenmiştir. İkinci yılda ise Albion çilek çeşidinin diğer çeşitlere göre daha yüksek verimde olduğu tespit edilmiştir. Tam sulama suyunda da en yüksek verime ulaşılmıştır.
Anahtar Kelimeler: *Çilek Çeşitleri, Kısıntılı Sulama, Niğde, Albion, San Andreas*

Giriş

Çilek (Fragaria × ananassa Duch.), dünya genelinde en fazla ıslah çalışması yapılan meyve türlerinden biri olup, yüksek ticari değeri ve geniş adaptasyon kabiliyeti sayesinde hem taze tüketim hem de işlenmiş ürün sanayiinde önemli bir yere sahiptir. Özellikle ABD'nin Kaliforniya ve Florida eyaletlerinde yürütülen yoğun ıslah çalışmaları sonucunda; yüksek verim, iri meyve, hastalık ve zararlılara dayanıklılık gibi üstün özelliklere sahip birçok yeni çeşit geliştirilmiş ve üreticilere sunulmuştur (Paydaş Kargı ve Sarıdaş, 2012). Türkiye'de ise çilek yetiştiriciliği başta Akdeniz Bölgesi olmak üzere Ege, Marmara, kısmen Karadeniz ve Doğu Anadolu Bölgelerinde yaygın olarak yapılmakta; kısa gün ve nötr-gün karakterine sahip çok sayıda ithal ve yerli çeşit yetiştirilmektedir.
Birleşmiş Milletler Gıda ve Tarım Örgütü (FAO) verilerine göre Türkiye, 2019 yılında İspanya ve Çin'in ardından dünyanın üçüncü büyük çilek üreticisi konumuna yükselmiştir (Anonim, 2020). Türkiye'deki çilek üretiminde son yıllarda genel bir artış eğilimi gözlemlense de, 2023 yılında üretim miktarında yaklaşık %7'lik bir azalma yaşanmıştır. Bu dalgalanmaların altında yatan temel nedenlerden biri, tarımsal üretimde giderek artan su kısıtı ve kuraklık stresidir. Su, çilek bitkisinin büyüme ve gelişiminde en kritik girdilerden biri olup; sulama rejimi, hem verimi hem de meyve kalitesini doğrudan etkilemektedir.
Niğde ili, İç Anadolu Bölgesi'nin güneyinde yer almakta olup, karasal iklimi ve kısıtlı su kaynaklarına rağmen çilek yetiştiriciliği açısından son yıllarda dikkat çekici bir potansiyele sahiptir. TÜİK (2018) verilerine göre, özellikle Bor, Altunhisar ve Niğde Merkez ilçelerinde dekara 3000 kg'ı bulan verimlerle üretimde belirgin bir artış sağlanmıştır. Niğde'nin çilek üretiminde ön plana çıkması, bir yandan alternatif ürün desenlerinin geliştirilmesini sağlarken, diğer yandan sulama suyu yönetimi açısından sürdürülebilir stratejilerin geliştirilmesini zorunlu kılmaktadır.

Çilek çeşitleri, fotoperiyot duyarlılıklarına göre kısa gün, uzun gün ve nötr-gün olmak üzere sınıflandırılır. Hasat periyodunun uzatılmasında nötr-gün çeşitlerin önemi artmakta ve bu çeşitlerin ticari değeri gün geçtikçe yükselmektedir (Demirsoy vd., 2012). Ancak her yeni çilek çeşidi, bulunduğu çevresel koşullara aynı şekilde adapte olamayabilir. Bu nedenle, farklı bölgelerde yetiştirilecek çeşitlerin, ekolojik koşullara uygunluğunun test edilmesi, yani adaptasyon çalışmaları büyük önem taşımaktadır (Özbahçali ve Aslantaş, 2014).

Bu bağlamda, Niğde ili koşullarında yürütülen bu çalışma ile, nötr-gün karakterine sahip üç farklı çilek çeşidinin (Albion, Monterey ve San Andreas), üç farklı sulama düzeyinde (I100: tam sulama, I75: %75 sulama, I50: %50 sulama) gösterdikleri performans değerlendirilmiş; bitki başına verim, meyve sayısı, ortalama meyve büyüklüğü ve dekara verim gibi temel verim parametreleri üzerinden en uygun çeşit ve sulama düzeyinin belirlenmesi amaçlanmıştır.

Çalışmadan elde edilecek sonuçların, bir yandan su kullanım etkinliği yüksek üretim tekniklerinin geliştirilmesine katkı sağlaması, diğer yandan üretici bazında sürdürülebilir çilek yetiştiriciliği için yol gösterici olması beklenmektedir. Ayrıca, kısıntılı sulama koşullarında bile optimum verim düzeylerine ulaşılabilecek stratejilerin belirlenmesi, kuraklıkla mücadelede bölge çiftçisine önemli avantajlar sunabilecektir.

Materyal ve Metod

Deneme Lokasyonu

Araştırma Niğde, Ömer Halisdemir Üniversitesi Tarım Bilimleri ve Teknolojileri Fakültesi deneme alanında açık tarla arazisinde gerçekleştirilmiştir.

Toprak Özellikleri

Denemenin kurulduğu yer Niğde Ömer Halisdemir Üniversitesi Tarım Bilimleri ve Teknolojileri Fakültesi uygulama arazisidir. Denemeye konu olan toprak analizi Niğde İl Özel İdaresi Tarımsal Hizmetler Müdürlüğü Toprak ve Su Tahlil Laboratuvarında yapılmıştır. Analiz sonuçları Çizelge 1. de gösterilmiş olup toplam tuz 0,02 (Tuzsuz), pH değeri 7,9 (Hafif Alkali), Satürasyonu %51 (Killi-Tınlı), Kireç %21,9 (Fazla), alınabilir Potasyum'u 469 kg/dekar (Yüksek), organik madde %1 (Az) ve alınabilir Fosfor'u 18,9 kg/dekar (Çok Yüksek)'dir.

Çizelge 1. Ömer Halisdemir Üniversitesi Tarım Bilimleri ve Teknolojileri Fakültesi Araştırma ve Uygulama Arazisi toprak analiz sonuçları

VERİMLİLİK ANALİZİ	BİRİMİ	SONUÇ	AÇIKLAMA
Saturasyon	%	51	Killi-Tınılı
pH		7,9	Hafif Alkali
Toplam Tuz	%	0,02	Tuzsuz
Kireç (CaCo3)	%	21,9	Fazla
Organik Madde	%	1	Az
Alınabilir Fosfor (P2O5,)	kg/da	18,9	Çok Yüksek
Alınabilir Potasyum (K2O,)	kg/da	469	Yüksek

2.3. Kullanılan Çilek Çeşitlerinin Özellikleri

Bu çalışmada, İç Anadolu Bölgesi ekolojik koşullarına adaptasyon potansiyeli yüksek olan üç farklı nötr-gün çilek çeşidi kullanılmıştır: Albion, Monterey ve San Andreas. Söz konusu çeşitler, hem verim performansı hem de hastalıklara dayanıklılık düzeyleri açısından ticari öneme sahip genotiplerdir.

Albion çeşidi, 1999 yılında Kaliforniya Üniversitesi tarafından Diamante × Cal 94.16-1 melezlemesi sonucu geliştirilmiş bir çeşittir. Serin ve ılıman iklim koşullarında başarılı sonuçlar vermekte olup, sezon boyunca istikrarlı bir şekilde pazarlanabilir meyve üretme kapasitesine sahiptir. Verticillium, Phytophthora ve Antraknoz etmenlerine karşı dayanıklılık gösteren bu çeşit, külleme ve meyve antraknozuna karşı ise orta derecede hassasiyet taşımaktadır. Tat kalitesi iyi, meyve şekli düzgün ve iri yapıdadır.

Monterey çeşidi, Albion × Cal 97.85-6 melezinden elde edilmiş ve 2009 yılında Kaliforniya'da tescillenmiştir. Nötr-gün özellik gösteren bu çeşidin en belirgin özelliklerinden biri, düşük asit oranına bağlı olarak aromatik ve tatlı meyveler üretmesidir. Güçlü bir bitki yapısına sahip olan Monterey, külleme hastalığına karşı hassas olmakla birlikte diğer fungal etmenlere karşı genel olarak dayanıklılık göstermektedir. Meyveleri düzgün şekilli olup orta iriliktedir.

San Andreas ise Albion × Cal 97.86-1 melezlemesiyle geliştirilmiş bir diğer nötr-gün çilek çeşididir. Bu çeşit, özellikle iri ve açık renkli meyve yapısıyla öne çıkmaktadır. Mildiyö hastalığına karşı dayanıklı olan San Andreas, bazı virüs kaynaklı hastalıklara karşı hassasiyet gösterebilmektedir. Erken hasat potansiyeline sahip olup, tat kalitesi oldukça yüksek düzeydedir.

Üç çeşidin de foto-periyodik yapılarının nötr-gün olması, daha uzun ve esnek hasat dönemlerine olanak tanımakta; bu da onları Niğde gibi karasal iklim bölgelerinde yetiştiricilik açısından cazip hale getirmektedir.

Bölgenin İklimi

Denemenin yürütüldüğü Niğde ili, Türkiye'nin İç Anadolu Bölgesi'nde yer almakta olup karasal iklim kuşağında bulunmaktadır. Bölgenin hakim bitki örtüsü bozkırdır. Yaz ayları genellikle sıcak ve kurak geçerken, kış aylarında soğuk hava ve kar yağışları sıkça görülür. Yüksek rakımlı kesimlerde ise yayla iklimi etkisini göstermektedir (Anonim, 2024).

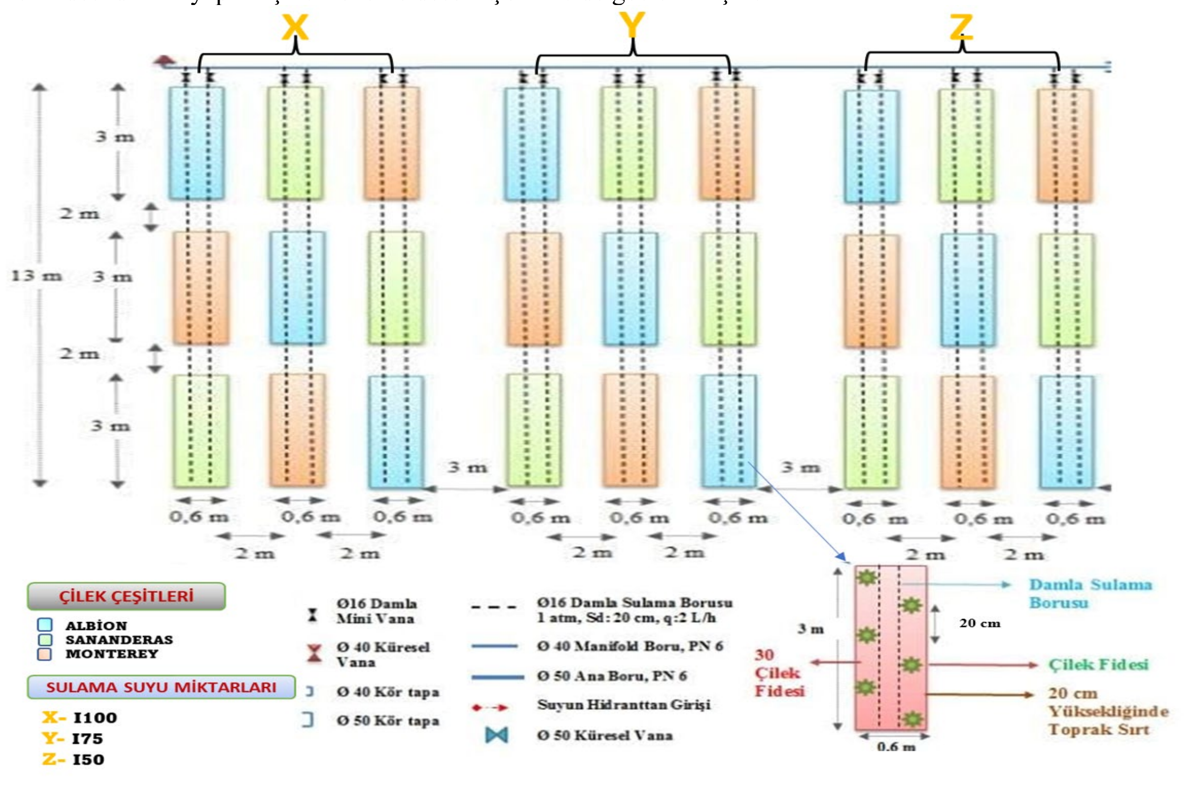
Uzun yıllara dayalı meteorolojik verilere göre, Niğde'de yıllık ortalama sıcaklık değeri yaklaşık 11,2 °C düzeyindedir. En yüksek sıcaklıklar temmuz ayında gözlenirken, en düşük sıcaklıklar ocak ayında ortaya çıkmaktadır. Yaz aylarında ortalama günlük güneşlenme süresi 11,5 saate kadar ulaşmakta, bu durum bitkisel üretim açısından avantaj sağlamaktadır. Yağış dağılımına bakıldığında, en fazla yağışlı gün sayısı ortalama 11,7 gün ile mayıs ayında gerçekleşmektedir.

Çalışmanın yürütüldüğü yıllara ait detaylı iklim verileri incelendiğinde; 2021 yılında en düşük sıcaklık şubat ayında -15 °C olarak kaydedilirken, 2022 yılında bu değer ocak ayında -20,3 °C'ye kadar düşmüştür. Her iki yılda da en yüksek sıcaklıklar ağustos ayında ölçülmüş; 2021 yılında 38,1 °C, 2022 yılında ise 36,1 °C olarak tespit edilmiştir. Yağış miktarları karşılaştırıldığında, 2021 yılında en fazla yağış aralık ayında (54,8 mm), 2022 yılında ise mayıs ayında (57,6 mm) gerçekleşmiştir.

Bu iklimsel özellikler, bölgedeki tarımsal faaliyetlerin planlanmasında sulama rejimlerinin önemini artırmakta; özellikle kurak yaz koşulları, çilek gibi suya duyarlı meyve türleri için etkili sulama stratejilerinin geliştirilmesini zorunlu kılmaktadır.

Denemenin Kurulması

Deneme tesadüf bloklarında bölünmüş parseller deneme desenine göre 3 tekerrürlü olarak kurulmuştur. Çalışmada sulama kısıtlı sulama uygulamaları değerlendirilmiştir. Çilek fidesi dikimi her sırta 2'şer sıra olmak üzere, sıra arası 30 cm, sıra üzeri 15 cm, parsellerin boyutları ise 60 cm x 3 m olarak planlanmıştır. Her bir toprak sırtında 30 çilek fidesi dikimi yapılmıştır. Deneme deseni Şekil 1.'de gösterilmiştir.



Şekil 1. Deneme deseni

Toprak Hazırlığı ve Dikim

10 Mayıs 2021 tarihinde Dikimden önce toprak traktörle sürülerek hazırlanmaya başlanmıştır. Yüksekliği 20 cm ve genişliği 60 cm 3 m uzunluğunda toprak sırtları oluşturulmuştur. Her sırta yanmış hayvan gübresi uygulanarak toprağın bitki besin madde içeriği zenginleştirilmiştir. Fide dikiminden önce naylon malçlama işlemi yapılmış olup fide dikim malçların üzerinde 30 cm aralıklarla açılmış deliklere toprak nemlendirilerek dikilmiştir. Bitkiler büyüyene kadar çiçekleri toplanmış ve meyveye oturması önlenmiştir.

Su Kullanımı ve Sulama Suyu Kullanım Randımanının Belirlenmesi (WUE ve IWUE)

Çileklerin tarla şartlarında yetiştirilmesi ve denemenin kurulması kapsamında tesadüfi blokları deneme desenine göre her bir çilek çeşidi ve uygulanacak sulama konularından 3 tekerrürlü ve her tekerrürde de 30 bitki olacak

şekilde planlanmıştır. Bitkilere uygulanacak sulama suyu için ise önceden yapılmış toprak bünye analize göre killi toprak olup infiltrasyon hızı 5 mm/saat olarak tespit edilmiştir (Kamber 2006). Ağır veya orta-ağır bünyeli topraklarda damlatıcı debisinin 2-4 L/h seçilmesi tavsiye edilmektedir (Kamber 2010). Buna göre Se= $0,9*(q/I)^{1/2}$ formülüne göre damlatıcı debisi 2L/h seçildiğinde damlatıcı aralığı 40 cm olarak hesaplanmaktadır ($Se=0.9*(2/10)^{1/2}$). Buna göre 1L/h debi verebilen ve 30 cm damlatıcı aralığında borular kullanılarak damla sulama sistemi tertip edilmiştir. Sulama suyu ve su tüketimi kullanım randımanlarını belirlemek amacıyla Howell ve ark. (1995)'nın verdiği eşitlikler kullanılmıştır.
IWUE = Y / I
Bu eşitliklerde:
IWUE: Sulama suyu kullanım randımanı (kg/m^3)
WUE =Y/ ET
WUE: Toplam su kullanım randımanı (kg/m^3)
ET: Evapotranspirasyon, (mm)
I: Uygulanan Sulama Suyu, (mm)
Y: Sulanan konularda elde edilen dane verimleridir (kg/da).

Sulama ve Gübreleme

Araştırmada üç farklı çilek çeşidi kullanılarak, tam (I100) ve iki düzeyde kısıntılı (I75 ve I50) olmak üzere üç farklı sulama rejimi uygulanmıştır. Sulama uygulamaları, Niğde Meteoroloji İl Müdürlüğü'nden temin edilen açık yüzey buharlaşma verileri esas alınarak yapılmış ve sulama aralıkları üç günde bir olacak şekilde düzenlenmiştir. Su uygulama miktarları, Class A Pan buharlaşma değerleri temel alınarak, bitki örtü oranı ve parsel alanına göre hesaplanmıştır. Parsellere damla sulama sistemiyle su verilmiş, her sıraya 3 m uzunluğunda iki lateral hat döşenmiştir. Deneme boyunca sulama suyu ve yağış miktarları izlenmiş ve su tüketimi "su bütçesi yöntemi" ile hesaplanmıştır.

Gübreleme uygulamaları ise toprak analiz sonuçlarına göre planlanmıştır. Organik maddece zayıf olan toprak yapısını iyileştirmek amacıyla dikim öncesinde dekara 3 kg olacak şekilde büyükbaş hayvan gübresi uygulanmış, ayrıca çeşitli mikro ve makro besin elementleri içeren organik sıvı gübrelerle sezon boyunca destekleme yapılmıştır. Uygulanan gübreler, başta azot, fosfor ve potasyum olmak üzere; demir, mangan, çinko, bakır gibi iz elementleri de içermektedir. Gübreleme, her iki yılda da belli aralıklarla ve farklı içeriklerle tekrarlanarak bitki gelişimi desteklenmiştir.

Verim Parametrelerinin Değerlendirilmesi ve İstatistiksel Analiz

Araştırmada çilek bitkilerinin verim performansını değerlendirmek amacıyla çeşitli morfolojik verim parametreleri ölçülmüştür. Her bir parselde üç tekerrürlü olarak yürütülen uygulamalarda, bitki başına verim, ortalama meyve büyüklüğü ve bitki başına meyve sayısı belirlenmiştir. Bitki başına verim, hasat edilen meyvelerin toplam ağırlığının beş rastgele seçilen bitki üzerinden ölçülmesiyle elde edilmiştir. Ortalama meyve büyüklüğü, seçilen bitkilerdeki meyve çapı ve boyu ayrı ayrı ölçülerek hesaplanmıştır. Ayrıca, aynı bitkiler üzerinden bitki başına düşen ortalama meyve sayısı belirlenmiştir.

Elde edilen verilerin istatistiksel değerlendirmesi MINITAB paket programı kullanılarak gerçekleştirilmiştir. Sulama düzeylerinin ve çilek çeşitlerinin verim parametreleri üzerindeki etkilerini ortaya koymak amacıyla varyans analizi yapılmış, gruplar arası farkların belirlenmesinde ise Tukey çoklu karşılaştırma testi uygulanmıştır. Analiz sonuçları, gruplar arasındaki farkların istatistiksel önem düzeylerini gösterecek şekilde değerlendirilmiştir.

Bulgular

Sulama Durumu

Bitkilerin su ihtiyacı yağış ve sulama suyu göz önüne alınarak belirlenmiştir. Deneme süresi boyunca uygulanan sulama suyu miktarları, sayıları ve sulama tarihleri Çizelge 2'de ve çizelge 3'te gösterilmiştir. Denemenin birinci yılında dikilen fidelere 30 Ağustos 2021 tarihine kadar tam sulama uygulanmış olup 1 Eylül 2021 tarihi itibariyle farklı sulama düzeyleri uygulamasına başlanmıştır. Dikim tarihlerinden itibaren farklı sulama düzeyi uygulamalarına kadar geçen sürede toplam 59.511 mm sulama suyu uygulanmıştır. 1 eylülden sonra ise tam sulama konusuna toplam 12.283 mm, %75 sulama konusuna toplam 9.212 mm ve %50 sulama konusuna ise toplam 6.141 mm su uygulanmıştır. 2021 yılı içinde tüm konulara uygulanan toplam su miktarı 87.147 mm'dir.

Çizelge 2. 2021 yılı farklı sulama düzeylerinde uygulanan su miktarı (mm)

Sulama Tarih	**Net evaporasyon (ETo-P) mm**	**Bitki Örtü Alanı m2**	**Net Evapotranspirasyon L/Bitki**	**Bitki Su İhtiyacı L/Bitki**	**%100 Sulama Miktarı L/bitki**	**%75 Sulama Miktarı**	**%50 Sulama Miktarı**
10.05.2021	16.0	0.07065	1.130	0.904	1.103		
12.05.2021	14.2	0.07065	1.003	0.803	0.979		
14.05.2021	16.0	0.07065	1.130	0.904	1.103		

17.05.2021	24.8	0.07065	1.752	1.402	1.709		
19.05.2021	15.0	0.07065	1.060	0.848	1.034		
21.05.2021	16.0	0.07065	1.130	0.904	1.103		
24.05.2021	22.6	0.07065	1.597	1.277	1.558		
26.05.2021	14.2	0.07065	1.003	0.803	0.979		
28.05.2021	16.0	0.07065	1.130	0.904	1.103		
31.05.2021	24.0	0.07065	1.696	1.356	1.654		
2.06.2021	16.0	0.07065	1.130	0.904	1.103		
4.06.2021	14.0	0.07065	0.989	0.791	0.965		
7.06.2021	23.0	0.07065	1.625	1.300	1.585		
9.06.2021	15.0	0.07065	1.060	0.848	1.034		
11.06.2021	4.2	0.07065	0.297	0.237	0.289		
14.06.2021	4.4	0.07065	0.311	0.249	0.303		
17.06.2021	5.8	0.07065	0.410	0.328	0.400		
19.06.2021	13.2	0.07065	0.933	0.746	0.910		
21.06.2021	14.0	0.07065	0.989	0.791	0.965		
23.06.2021	14.8	0.07065	1.046	0.836	1.020		
25.06.2021	13.4	0.07065	0.947	0.757	0.924		
28.06.2021	16.0	0.07065	1.130	0.904	1.103		
30.06.2021	16.0	0.07065	1.130	0.904	1.103		
2.07.2021	17.0	0.07065	1.201	0.961	1.172		
5.07.2021	25.6	0.07065	1.809	1.447	1.765		
7.07.2021	16.0	0.07065	1.130	0.904	1.103		
10.07.2021	27.0	0.07065	1.908	1.526	1.861		
12.07.2021	19.2	0.07065	1.356	1.085	1.323		
15.07.2021	20.0	0.07065	1.413	1.130	1.379		
17.07.2021	30.0	0.07065	2.120	1.696	2.068		
19.07.2021	20.4	0.07065	1.441	1.153	1.406		
21.07.2021	20.4	0.07065	1.441	1.153	1.406		
23.07.2021	19.6	0.07065	1.385	1.108	1.351		
25.07.2021	19.6	0.07065	1.385	1.108	1.351		
27.07.2021	17.0	0.07065	1.201	0.961	1.172		
30.07.2021	25.0	0.07065	1.766	1.413	1.723		
2.08.2021	24.0	0.07065	1.696	1.356	1.654		
5.08.2021	24.0	0.07065	1.696	1.356	1.654		
8.08.2021	26.0	0.07065	1.837	1.470	1.792		
10.08.2021	8.2	0.07065	0.579	0.463	0.565		
12.08.2021	11.6	0.07065	0.820	0.656	0.800		
15.08.2021	18.2	0.07065	1.286	1.029	1.254		
18.08.2021	23.0	0.07065	1.625	1.300	1.585		
21.08.2021	23.2	0.07065	1.639	1.311	1.599		
24.08.2021	26.0	0.07065	1.837	1.470	1.792		
27.08.2021	26.8	0.07065	1.893	1.515	1.847		
30.08.2021	27.0	0.07065	1.908	1.526	1.861		
2.09.2021	27.0	0.07065	1.908	1.526	1.861	1.396	0.931
5.09.2021	24.0	0.07065	1.696	1.356	1.654	1.241	0.827
8.09.2021	21.2	0.07065	1.498	1.198	1.461	1.096	0.731
11.09.2021	23.0	0.07065	1.625	1.300	1.585	1.189	0.793
14.09.2021	22.0	0.07065	1.554	1.243	1.516	1.137	0.758
17.09.2021	6.2	0.07065	0.438	0.350	0.427	0.321	0.214
20.09.2021	7.2	0.07065	0.509	0.407	0.496	0.372	0.248
23.09.2021	13.0	0.07065	0.918	0.735	0.896	0.672	0.448
26.09.2021	10.6	0.07065	0.749	0.599	0.731	0.548	0.365
29.09.2021	12.0	0.07065	0.848	0.678	0.827	0.620	0.414
2.10.2021	12.0	0.07065	0.848	0.678	0.827	0.620	0.414
Toplam			**73.589**	**58.871**	**71.794**	**9,212**	**6,141**

1*Kc Değeri :0.8 2*Sulama Suyu Randımanı: 0.82

Denemenin ikinci yılında 11 Temmuz 2022 tarihine kadar bütün konulara tam su verilmiştir. Geçen bu sürede uygulanan toplam su miktarı 12,379 mm'dir. 12 temmuzdan sonra ise tam sulama konusuna toplam 43,376 mm, %75 sulama konusuna toplam 32.532 mm ve %50 sulama konusuna ise toplam 21.688 mm su uygulanmıştır. 2022 yılı içinde tüm konulara uygulanan su miktarı toplamı 97.596 mm'dir.

Çizelge 3. 2022 yılı farklı sulama düzeylerinde uygulanan su miktarı (mm)

Sulama Tarih	Net evaporasyon (ETo-P) mm	Bitki Örtü Alanı m2	Net Evapotranspirasyon L/Bitki	Bitki Su İhtiyacı L/Bitki	%100 Sulama Miktarı L/bitki	%75 Sulama Miktarı	%50 Sulama Miktarı
12.06.2022	11.7	0.07065	0.827	0.661	0.806		
15.06.2022	19.8	0.07065	1.399	1.119	1.365		
18.06.2022	0.0	0.07065	0.000	0.000	0.000		
21.06.2022	21.2	0.07065	1.498	1.198	1.461		
24.06.2022	24.6	0.07065	1.738	1.390	1.696		
27.06.2022	21.4	0.07065	1.512	1.210	1.475		
30.06.2022	19.6	0.07065	1.385	1.108	1.351		
3.07.2022	15.8	0.07065	1.116	0.893	1.089		
6.07.2022	21.7	0.07065	1.533	1.226	1.496		
9.07.2022	23.8	0.07065	1.681	1.345	1.640		
12.07.2022	22.7	0.07065	1.604	1.283	1.565	1.173	0.782
15.07.2022	24.2	0.07065	1.710	1.368	1.668	1.251	0.834
18.07.2022	25.0	0.07065	1.766	1.413	1.723	1.292	0.862
21.07.2022	24.6	0.07065	1.738	1.390	1.696	1.272	0.848
24.07.2022	24.0	0.07065	1.696	1.356	1.654	1.241	0.827
27.07.2022	24.8	0.07065	1.752	1.402	1.709	1.282	0.855
30.07.2022	24.8	0.07065	1.752	1.402	1.709	1.282	0.855
2.08.2022	29.8	0.07065	2.105	1.684	2.054	1.541	1.027
5.08.2022	30.2	0.07065	2.134	1.707	2.082	1.561	1.041
8.08.2022	30.8	0.07065	2.176	1.741	2.123	1.592	1.061
11.08.2022	30.4	0.07065	2.148	1.718	2.095	1.572	1.048
14.08.2022	30.8	0.07065	2.176	1.741	2.123	1.592	1.061
17.08.2022	31.4	0.07065	2.218	1.775	2.164	1.623	1.082
20.08.2022	32.6	0.07065	2.303	1.843	2.247	1.685	1.124
23.08.2022	29.6	0.07065	2.091	1.673	2.040	1.530	1.020
26.08.2022	30.8	0.07065	2.176	1.741	2.123	1.592	1.061
29.08.2022	30.2	0.07065	2.134	1.707	2.082	1.561	1.041
1.09.2022	30.0	0.07065	2.120	1.696	2.068	1.551	1.034
4.09.2022	30.8	0.07065	2.176	1.741	2.123	1.592	1.061
7.09.2022	28.0	0.07065	1.978	1.583	1.930	1.447	0.965
10.09.2022	23.2	0.07065	1.639	1.311	1.599	1.199	0.800
13.09.2022	21.0	0.07065	1.484	1.187	1.447	1.086	0.724
16.09.2022	19.6	0.07065	1.385	1.108	1.351	1.013	0.675
Toplam			**57.149**	**45.719**	**55.755**	**32.532**	**21.688**

1*KcDeğeri :0.8 2*Sulama Suyu Randımanı: 0.82

3.2. Su Kullanımı ve Sulama Suyu Kullanım Randımanı Değerleri (WUE ve IWUE)

Su kaynaklarının Dünya genelinde giderek azalması sebebiyle, su kullanımının en aza indirme stratejileri geliştirmek (Liu ve ark, 2007) sulama mühendisliğinde en güncel konular arasında yer almaktadır. Sulama suyu kullanım randımanı bu stratejileri geliştirmek için kullanılan en önemli argümanlardan bir tanesidir. Çalışmamızda kullanılan deneme konusuna ait su kullanımı ve sulama suyu kullanım randımanı çizelge 4 ve çizelge 5'te gösterilmiştir. 2021 Sulama düzeylerinde su kullanım randımanı değerlerine bakıldığında Çizelge 4.3 'te en yüksek değere 3.65 g/mm ile Monterey çeşidinde %50 sulama düzeyinde rastlanırken en düşük değere 1.31 g/mm ile San Andreas çeşidinde %75 sulama düzeyinde rastlanmıştır. Sulama suyu kullanım randımanı değerleri göz önüne alındığında ise en yüksek değere %50 sulama düzeyinde 2.99 g/mm ile Monterey çeşidinde görülürken en düşük %75 sulama düzeyinde 1.07 g/mm ile San Andreas çeşidinde görülmüştür.

Çizelge 4. 2021 yılı su kullanımı ve sulama suyu kullanım randımanı değerleri(WUE ve IWUE)

SULAMA DÜZEYLERİ 2021	KONU	ÇEŞİTLER	VERİM (gr/bitki)	Bitki Su İhtiyacı L/Bitki	WUE	Sulama Miktarı L/bitki	IWUE
	%100 SULAMA	ALBİON	159.6		2.71		2.22
		MONTEREY	176.5	58.87	3.00	71.79	2.46
		SAN ANDREAS	88.4		1.50		1.23
	%75 SULAMA	ALBİON	92.3		2.09		1.71
		MONTEREY	136.1	44.15	3.08	53.85	2.53
		SAN ANDREAS	57.8		1.31		1.07
	%50 SULAMA	ALBİON	88.3		3.00		2.46
		MONTEREY	107.5	29.44	3.65	35.90	2.99
		SAN ANDREAS	51.2		1.74		1.43

2022 Sulama düzeylerinde su kullanım randımanı değerlerine bakıldığında (Çizelge 5) en yüksek değere Albion çeşidinde %50 sulama düzeyinde rastlanırken en düşük değere San Andreas çeşidinde %50 sulama düzeyinde rastlanmıştır. Sulama suyu kullanım randımanı değerleri göz önüne alındığında ise en yüksek değere %50 sulama düzeyinde Albion çeşidinde görülürken en düşük %75 sulama düzeyinde San Andreas çeşidinde görülmüştür.

Çizelge 5. 2022 yılı su kullanımı ve sulama suyu kullanım randımanı değerleri(WUE ve IWUE)

SULAMA DÜZEYLERİ 2022	KONU	ÇEŞİTLER	VERİM (gr/bitki)	Bitki Su İhtiyacı L/Bitki	WUE	Sulama Miktarı L/bitki	IWUE
	%100 SULAMA	ALBİON	173.1	45.72	3.79	55.75	3.11
		MONTEREY	134.8		2.95		2.42
		SAN ANDREAS	82.1		1.80		1.47
	%75 SULAMA	ALBİON	151.9	34.29	4.43	41.82	3.63
		MONTEREY	135.3		3.95		3.24
		SAN ANDREAS	57.1		1.66		1.36
	%50 SULAMA	ALBİON	111.3	22.86	4.87	27.88	3.99
		MONTEREY	98.8		4.32		3.54
		SAN ANDREAS	48.0		2.10		1.72

Verim Analizleri

Yaptığımız çalışma sonucunda incelenen çilek türlerinin ortalama meyve ağırlığı açısından sulama suyu miktarına duyarlı olduğu görülmektedir. Çilek çeşitlerine uygulanan su miktarının verim değerlerine etkisinin önemli olduğu belirlenmiştir. Çalışma sonucunda uygulanan tam sulama kısıtlı sulama uygulamalarıyla karşılaştırıldığında önemli farklılıklar gözlemlenmiştir. Tam sulama uygulamasının kısıtlı sulama uygulamalarına göre daha fazla verim verdiği tespit edilmiştir. Su stresinin artması verimi azaltmıştır (Kaman vd., 2023). Bu doğrultuda diğer literatür çalışmalarıyla benzer değerler elde edilmiştir. 2021 yılı verim değerlerine göre en yüksek verim 176.5 gr ile Monterey çilek çeşidinden elde edilirken 2022 yılında en yüksek verim 173.1 gr ile Albion çilek çeşidinden elde edilmiştir. Yozgat ilinde yapılan iki yıl yürütülen bir çalışmada da ilk yıl Monterey çilek çeşidinde verim değeri fazla çıkarken ikinci yıl Albion çilek çeşidinde verim değeri daha fazla çıkmış olup benzer sonuçlar görülmektedir (Balcı, vd.,2017).

Hem küresel olarak hem de ülkemiz açısından bakıldığında tatlı suyun bir kısmı tarımsal üretimde kullanılmaktadır. Tarım yapılan yerler su stresi yaşanan bölgelerde yer almakta olup, bu bölgelerde sulama için kullanılan su azalmaktadır ve sulama kısıtlamalarına tabi tutulmaktadır(Ariza ve ark., 2021). Tarımla meşgul olmanın temel amaçlarından biri yüksek verimde ürünler elde etmektir (Yuan ve Ark, 2004). Bu yüzden bitki verimi üzerinde sulama ile ilgili çalışmalar yapılmaktadır.

2021 yılında yapılan sulama düzeyi uygulamalarının bitki başına toplam verim değerlerine etkisine ait varyans analiz sonuçları Çizelge 6'da verilmiştir. Çeşitler ve Sulama Düzeyleri kendi aralarında değerlendirildiğinde %1 seviyesinde istatistiksel farklılık görülmüştür. Sulama Düzeyleri*Çeşit karşılaştırmasında da %5 seviyesinde istatiksel fark bulunmuştur.

Çizelge 6. 2021 yılı farklı sulama düzeyinin bitki başına toplam verime etkisi varyans analiz sonucu

Varyasyon Kaynağı	Serbestlik Derecesi	Kareler Ortalaması	F- Değeri	
Çeşit	2	12745.9	56.76	**

Sulama Düzeyleri	2	8702.2	83.07	**
Sulama Düzeyleri*Çeşit	4	451.2	2.94	*
Hata	18	153.3		
Toplam	26			
*** %5, ** %1 Seviyesinde Önemli (ANOVA)**				

Çizelge 7'de verilen değerlere göre en yüksek verim Monterey 176.5 (g/bitki) çeşidinde ve I_{100} 'de görülmüştür. En düşük verim ise I_{50} 'de San Andreas (51.1 g/bitki) çeşidinde tespit edilmiştir. Su stresi altındaki bitkilerde toplam meyve ağırlığında azalma görüldü. Bu yönüyle Gehrmann' ın yaptığı çalışmayla benzerlik görülmüştür (Gehrmann, 1985).

Çizelge 7. 2021 yılı sulama düzey*çeşit karşılaştırmasının bitki başına düşen ortalama verim değerleri (g/bitki)

SULAMA DÜZEYLERİ/ ÇEŞİTLER	**ALBİON**	**MONTEREY**	**SAN ANDREAS**
%100 SULAMA	159.6 ab	176.5 a	88.4 de
%75 SULAMA	92.33 de	136.1 bc	57.8 ef
%50 SULAMA	88.2 de	107.5 cd	51.1 f
1: Farklar ayrı harflerle gösterilen değerler Tukey Çoklu Karşılaştırma Testine Göre %5 seviyesinde farklıdır.			

2022 yılında yapılan sulama suyu düzeyi uygulamalarının bitki başına toplam verim değerlerine etkisine ait varyans analiz sonuçları Çizelge 8'de verilmiştir. Çeşitler, Sulama Düzeyleri ve Sulama Düzeyleri*Çeşit karşılaştırmaları kendi aralarında değerlendirildiğinde %1 seviyesinde istatistiksel farklılık görülmüştür.

Çizelge 8. 2022 yılı farklı sulama düzeylerinin bitki başına toplam verime etkisi varyans analiz sonucu

Varyasyon Kaynağı	**Serbestlik Derecesi**	**Kareler Ortalaması**	**F- Değeri**	
Çeşit	2	16596.6	57.8	**
Sulama Düzeyleri	2	4489.6	213.8	**
Sulama Düzeyleri*Çeşit	4	362.9	4.67	**
Hata	18	77.6		
Toplam	26			
*** %5, ** %1 Seviyesinde Önemli (ANOVA)**				

Çizelge 9'daki verilere göre %100 sulama da Albion çilek çeşidi 173.1 g ile en yüksek meyve ağırlığına sahip olmuştur, en düşük meyve ağırlığı ise San Andreas çilek çeşidinde ve %50 kısıtlı sulama da tespit edilmiştir. Görüldüğü üzere daha fazla sulama suyu uygulamak, daha fazla meyve ağırlığı elde edildiğini bu sebeple daha fazla verim elde edildiğini göstermektedir. Elde edilen sonuçlar doğrultusunda diğer literatür çalışmalarında da aynı sonuçlarla karşılaşıldığı tespit edilmiştir (Krüger vd., 2012: Save vd., 1993).

SULAMA DÜZEYİ/ ÇEŞİTLER	**ALBİON**	**MONTEREY**	**SAN ANDREAS**
%100 SULAMA	173.1 a	134.8 bc	82.1 ef

%75 SULAMA	151.9 ab	135.3 bc	57.0 fg
%50 SULAMA	111.2 cd	98.8 de	48.0 g
1: Farklar ayrı harflerle gösterilen değerler Tukey Çoklu Karşılaştırma Testine Göre %5 seviyesinde farklıdır.			

Çizelge 9. 2022 yılı sulama düzey*çeşit karşılaştırmasının bitki başına düşen ortalama verim değerleri (g/bitki)

Yapılan çalışmada sulama düzeylerine ait 2 yıllık verilerin bitki başına ortalama toplam meyve ağırlık değerleri ve bitki başına ortalama meyve adedi gözlenmiştir. Elde edilen veriler göz önüne alındığında birinci yıl bitki başına verim değeri en yüksek Monterey (173,1 (g/bitki)) çeşidinde görülürken ikinci yıl en yüksek Albion (173,1 (g/bitki) çeşidinde görülmüştür. Ateş'in (2015) yaptığı çalışma sonucunda da çeşitler içinden en yüksek değer birinci deneme yılında Monterey'den (700.00 g/bitki) ve ikinci deneme yılında da en yüksek Albion'dan (740.31 g/bitki) elde edilmiştir. Yine birinci ve ikinci yılda elde ettiğimiz verilere göre en yüksek verim değerleri ve ortalama meyve adedi değerleri Tam Sulama (%100)'dan edildiği görülmüştür. Bitki başına düşen ortalama meyve adedi her iki yılda da en yüksek Monterey çilek çeşidinde görüşmüştür ve bu sonuç doğrultusunda literatürde de benzerlik bulunmuştur (Geçer vd., 2018). Her iki yılda da en düşük değer Kısıtlı Sulama (%50)'da San Andreas (51,1 (g/bitki) - 48 (g/bitki)) çeşidinde olduğu tespit edilmiştir.

Meyve Sayısı Değerleri (adet/bitki)

2021 yılı sulama düzeylerinin bir bitki başına ortalama meyve değerleri varyans analiz sonucu Çizelge 10' da verilmiştir. Varyans analizine göre çeşitler, sulama düzeyleri ve sulama düzeyi*çeşit karşılaştırmaları %1 seviyesinde önemli bulunmuştur.

Çizelge 10. 2021 yılı farklı sulama düzeylerinin bitki başına ortalama meyve sayısına etkisi varyans analiz sonucu

Varyasyon Kaynağı	**Serbestlik Derecesi**	**Kareler Ortalaması**	**F- Değeri**	
Çeşit	2	71.2	353.9	**
Sulama Düzeyleri	2	56.2	279.2	**
Sulama Düzeyi*Çeşit	4	1.1	5.5	**
Hata	18	0.2		
Toplam	26			
*** %5, ** %1 Seviyesinde Önemli (ANOVA)**				

2021 yılı sulama düzeyinde düzey*çeşit karşılaştırmasında Çizelge 11.'de verilenlere göre en yüksek meyve adedi Tam Sulama (%100 Sulama)'da Monterey (16.3 (adet/bitki)) çeşidinde görülmüştür. Elde edilen veriler doğrultusunda sulama suyu miktarının meyve adedi üzerine etkisi olumlu bulunmuştur. Şahiner'in 2019 'da yaptığı çalışmada da daha fazla sulama suyu uygulamanın daha fazla meyve üretmede önemli bir faktör olduğu görülmüştür (Şahiner, 2019).

Çizelge 11. 2021 yılı sulama düzey*çeşit karşılaştırmasının bitki başına düşen ortalama meyve sayısına etkisi (adet/bitki)

SULAMA DÜZEYLERİ/ ÇEŞİTLER	**ALBİON**	**MONTEREY**	**SAN ANDREAS**
%100 SULAMA	14.1 b	16.3 a	11.5 c
%75 SULAMA	11.4 c	14.6 b	7.6 e
%50 SULAMA	9.3 d	11.3 c	6.3 f
1: Farklar ayrı harflerle gösterilen değerler Tukey Çoklu Karşılaştırma Testine Göre %5 seviyesinde farklıdır.			

2022 yılı sulama düzeylerinin bir bitki başına ortalama meyve değerleri varyans analiz sonucu Çizelge 12' de verilmiştir.

Varyans analizine göre çeşitler, sulama düzeyleri ve sulama düzeyi*çeşit karşılaştırmaları %1 seviyesinde önemli bulunmuştur.

Çizelge 12. 2022 yılı farklı sulama düzeylerinin bitki başına ortalama meyve sayısına etkisi varyans analiz

Varyasyon Kaynağı	Serbestlik Derecesi	Kareler Ortalaması	F- Değeri	
Çeşit	2	110.5	396.7	**
Sulama Düzeyleri	2	63.5	277.9	**
Sulama Düzeyi*Çeşit	4	2.1	7.6	**
Hata	18	0.3		
Toplam	26			
*** %5, ** %1 Seviyesinde Önemli (ANOVA)**				

sonucu

2022 yılı sulama düzeylerinin bir bitki başına ortalama meyve değerleri Çizelge 13. ‘de gösterilmiştir. Monterey çeşidi (16.4 adet/bitki) Tam sulama (%100 sulama)’da ilk grupta yer alırken hemen arkasında Albion çeşidi (16.3 adet/bitki) Tam sulama (%100 sulama)’da yer aldığı görülmektedir. En düşük meyve adedi ise Kısıtlı Sulama (%50 Sulama)’da San Andreas çeşidinde gözlemlenmiştir. Uygulanan su miktarı meyve adedini etkilemiş ve daha fazla su uygulamasında daha fazla meyve adedi görülmüştür. Sarwari’nin yaptığı çalışmada da aynı doğrultuda daha fazla sulamanın meyve adedini arttırdığı gözlemlenmiştir (Sarwari, 2020).

Çizelge 13. 2022 yılı sulama düzey*çeşit karşılaştırmasının bitki başına düşen ortalama meyve sayısına etkisi (adet/bitki)

SULAMA DÜZEYLERİ/ ÇEŞİTLER	ALBİON	MONTEREY	SAN ANDREAS
%100 SULAMA	16.3 ab	16.4 a	10.5 d
%75 SULAMA	14.8 bc	13.7 c	6.8 e
%50 SULAMA	11.2 d	10.2 d	5.9 e
1: Farklar ayrı harflerle gösterilen değerler Tukey Çoklu Karşılaştırma Testine Göre %5 seviyesinde farklıdır.			

4.5

Meyve Büyüklüğü Değerleri

Meyve Boyu

2021 yılı sulama düzeylerine göre meyve boyu değerleri analiz Çizelgesi 14. ‘te gösterilmiştir. Çeşit ve sulama düzeyleri kendi aralarında incelendiğinde %5 seviyesinde farklılık görülmüştür ancak çeşit*sulama düzeyi karşılaştırmasında farklılık görülmemiştir.

Varyasyon Kaynağı	Serbestlik Derecesi	Kareler Ortalaması	F- Değeri	
Çeşit	2	49.6	4.1	*
Sulama Düzeyleri	2	56.6	4.7	*
Sulama Düzeyi*Çeşit	4	1.5	0.13	
Hata	18	12		
Toplam	26			

*** %5, ** %1 Seviyesinde Önemli (ANOVA)**

Çizelge 14. 2021 yılı farklı sulama düzeylerinde bitki başına düşen ortalama meyve boyuna etkisi varyans analiz sonucu

Çizelge 15'e göre çeşitler arasında en büyük boya sahip Albion (28.5 mm/bitki) çilek çeşidi, en küçük boya sahip San Andreas (23.9 mm/bitki) çilek çeşidi olmuştur. Çeşitler arasındaki meyve boyları karşılaştırıldığında Albion çilek çeşidi diğer iki çeşide göre daha büyük boya sahip olduğu görülmektedir. Daha önce yapılan çalışmada meyve boy oranlarının çeşitlere göre sıralaması Albion >Monterey > San Andreas şeklinde bulunmuştur (Geçer vd., 2018).

ÇEŞİTLER	**Ortalama Boy**
ALBİON	28.6 a
MONTEREY	27.7 ab
SAN ANDREAS	23.9 c
1: Farklar ayrı harflerle gösterilen değerler Tukey Çoklu Karşılaştırma Testine Göre %5 seviyesinde farklıdır.	

Çizelge 15. 2021 yılı üretilen çilek çeşitlerinin bitki başına düşen ortalama meyve boyu değerleri (mm/bitki)

Sulama düzeyleri arasındaki farklılığa göre bütün çeşitler aynı grupta yer almıştır. Çizelge 16'ya göre değerlere baktığımız da ise en yüksek değere 28.1 mm ile tam sulamada en düşük değere ise 24 mm ile kısıtlı sulamada (%50) rastlanmıştır. Bu bağlamda diğer literatürler ile karşılaştırıldığında sulama suyu miktarı azaldıkça meyve boyunun da azaldığı gözlemlenmiştir (Kaman vd., 2023).

SULAMA DÜZEYLERİ	**Ortalama Boy**
%100 SULAMA	28.1 a
%75 SULAMA	28 a
%50 SULAMA	24 a
1: Farklar ayrı harflerle gösterilen değerler Tukey Çoklu Karşılaştırma Testine Göre %5 seviyesinde farklıdır.	

Çizelge 16. 2021 yılı farklı sulama düzeylerinin bitki başına düşen ortalama meyve boyu değerleri (mm/bitki)

Meyve Çapı

2021 yılı sulama düzeylerine göre meyve çapı değerleri analiz Çizelgesi 17. 'de gösterilmiştir. Yapılan analize göre karşılaştırmalar sonucunda önemli farklılığa rastlanmamıştır.

Çizelge 17. 2021 yılı farklı sulama düzeylerinde bitki başına düşen ortalama meyve çapına etkisi varyans analiz sonucu

Varyasyon Kaynağı	Serbestlik Derecesi	Kareler Ortalaması	F- Değeri	
Çeşit	2	15.2	1.5	
Sulama Düzeyleri	2	32.1	3.2	
Sulama Düzeyi*Çeşit	4	13.8	1.4	
Hata	18	9.9		
Toplam	26			
*** %5, ** %1 Seviyesinde Önemli (ANOVA)**				

2022 yılı sulama düzeylerine göre meyve boyu değerleri analiz Çizelgesi 18. ‘de gösterilmiştir. Çizelgesi göre Çeşitler arasında yapılan karşılaştırmada %5 seviyesinde önemli bulunmuştur.

Çizelge 18. 2022 yılı farklı sulama düzeylerinde bitki başına düşen ortalama meyve boyuna etkisi varyans analiz sonucu

Varyasyon Kaynağı	Serbestlik Derecesi	Kareler Ortalaması	F- Değeri	
Çeşit	2	37.8	10.92	*
Sulama Düzeyleri	2	3.5	1	
Sulama Düzeyi*Çeşit	4	4.8	1.4	
Hata	18	3.5		
Toplam	26			
*** %5, ** %1 Seviyesinde Önemli (ANOVA)**				

Çizelge 19. ‘a göre Albion ve Monterey ilk grupta yer almıştır. Değerler karşılaştırıldığında 2022 yılında en yüksek boy değerine Monterey çilek çeşidi sahipken en düşük boy değerine San Andreas sahip olmuştur.

Çizelge 19. 2022 yılı üretilen çilek çeşitlerinin sulama düzeylerinde bitki başına düşen ortalama meyve boyu değerleri (mm/bitki)

ÇEŞİTLER	Ortalama Boy
ALBİON	29.4 a
MONTEREY	30.0 a
SAN ANDREAS	26.2 b
1: Farklar ayrı harflerle gösterilen değerler Tukey Çoklu Karşılaştırma Testine Göre %5 seviyesinde farklıdır.	

Meyve Çapı

2022 yılı sulama düzeylerine göre meyve çapı değerleri analiz Çizelgesi 20. ‘de gösterilmiştir. Analize göre sadece Çeşitler arası yapılan karşılaştırma %5 seviyesinde önemli bulunmuştur.

Çizelge 20. 2022 yılı farklı sulama düzeylerinde bitki başına düşen ortalama meyve çapına etkisi varyans analiz sonucu

Varyasyon Kaynağı	Serbestlik Derecesi	Kareler Ortalaması	F- Değeri	
Çeşit	2	47.2	6.2	*
Sulama Düzeyleri	2	0.4	0.05	
Sulama Düzeyi*Çeşit	4	5.8	0.7	
Hata	18	7.5		
Toplam	26			
*** %5, ** %1 Seviyesinde Önemli (ANOVA)**				

Çizelge 21.'de gösterildiği gibi Albion birinci grupta yer almıştır. Meyve çapı değerleri karşılaştırıldığında büyükten küçüğe Albion > Monterey > San Andreas şeklinde olduğu görülmektedir. Yapılan bir çalışmada benzer değerler bulunmuştur(Geçer vd., 2018). Buda yaptığımız çalışmanın literatüre uygun olduğunu göstermektedir.

Çizelge 21. 2022 yılı üretilen çilek çeşitlerinin (sulama düzeylerinde) bitki başına düşen ortalama meyve çapı

ÇEŞİTLER	Ortalama Çapı
ALBİON	27.7 a
MONTEREY	25.6 ab
SAN ANDREAS	23.1 b
1: Farklar ayrı harflerle gösterilen değerler Tukey Çoklu Karşılaştırma Testine Göre %5 seviyesinde farklıdır.	

değerleri (mm/bitki)

Sonuç

Çilek sağlık açısından sağladığı avantajlarla birlikte sanayide (gıda, ilaç, kozmetik…) de önemli bir üründür. Aynı zamanda kar marjı olarak yüksek gelir getiren ürünler arasında görülmektedir. Bu durum aile işgücüne de katkı sağlamaktadır. Çilek meyvesinin taşıma şartlarının zorluğu ve depolamada ürün kaybı göz önüne alındığında bölgede yetiştirilmeye teşviki ürün fiyat ve kalitesi açısından büyük kar sağlayacaktır.

Niğde iklim koşullarında 2021-2022 yıllarında 2 yıl süreyle yürütülen çalışma da sulama düzeylerinde ise Tam Sulama (%100) uygulanan çileklerin verimlerinin daha yüksek olduğu gözlemlenmiştir. Bu doğrultuda Niğde ili için en iyi sulama seviyesi tam sulama olarak sonuca ulaştırılmıştır buda gelecekteki çalışmalarda Tam Sulama (%100) uygulamasının kullanılacağını göstermiştir.

Çilek çeşitleri karşılaştırıldığında ilk yıl verim olarak en yüksek Monterey çeşidinde ve ikinci yıl ise en yüksek verim Albion çeşidinde olduğu tespit edilmiştir. Her iki yılda da irilikler karşılaştırıldığında çok önemli farklar olmamakla birlikte iki yılın yüksek meyve sayısı Monterey çeşidinde görülmüştür. Bölge de yetiştirilmesi istenen çeşit eğer tek yıllık olarak değerlendirilecekse Monterey çeşidi, eğer 2 yıllık dikim yapılacaksa Albion çeşidi uygun bulunmuştur.

Teşekkür: Bu çalışma Niğde Ömer Halisdemir Üniversitesi Bilimsel Araştırmalar Koordinasyon Biriminin TGT 2020/3-BAGEP nolu projesi tarafından desteklenmiştir. Çalışma, Niğde Ömer Halisdemir Üniversitesi Fen Bilimleri Enstitüsü Bitkisel Üretim ve Teknolojileri Anabilim Dalı'nda yürütülen"Niğde Koşullarında Kısıntılı Sulamanın Bazı Çilek Çeşitlerinde Verim Parametrelerine Etkileri" isimli yükseklisans tez çalışmasından alınmıştır.

Kaynaklar

Anonim 1, Çilek İstatistikleri, https://www.statagri.com/cilek-istatistikleri/, 15 Eylül 2024.

Anonim 2, Niğde'yi Tanıyalım, https://nigde.tarimorman.gov.tr/Menu/10/Nigdeyi-Taniyalim#:~:text=Bu%20durumda%20Ni%C4%9Fde'nin%20genel,k%C4%B1%C5%9F%C4%B1n%2C%20ya%C4%9Fmur%20halinde%20ilkbaharda%20rastlanmaktad%C4%B1r.&text=Ni%C4%9Fde%20kuzey%20yar%C4%B1mk%C3%BCrenin%20orta%20ku%C5%9Fa%C4%9F%C4%B1nda,ortalamas%C4%B1%20ise%20Ocak%20ay%C4%B1na%20rastlar, 14 Kasım 2023.

Ariza , M. T., Miranda L., Gómez-Mora J.A. , Medina J.J., Lozano D., Gavilán P., Soria C. ve Martínez-Ferri E., '' Yield and fruit quality of strawberry cultivars under different ırrigation regimes'' ***Agronomy Dergisi,*** 11,261 s. 2-23, Huelva (in Europe), 2021.

Ateş, K., Demirkıran, A. R., ve İnik, O., ''Toprağa bazı doğal ve yapay gübre ilavelerinin çilek bitkisinin verim parametreleri üzerine olan etkileri'', ***Türk Doğa ve Fen Dergisi***, 8, s. 23-28, Bingöl, 2019.

Ateş, S., Nevşehir ili organik çilek yetiştiriciliğinde kullanılabilecek farklı gübre ve malç materyallerinin verim ve kalite özellikleri üzerine etkileri, Doktora Tezi, ***Çukurova Üniversitesi Fen Bilimleri Enstitüsü***, Adana, s. 61,2015.

Balcı, G., Koç, A., Keles, H. ve Kılıç, T., ''Yozgat koşullarında bazı çilek çeşitlerinin performanslarının değerlendirilmesi'', ***Araştırma Makalesi,*** 4(2)*, s. 6-12,* Yozgat, 2017.

Demirsoy, L., Öztürk, A., Serçe, S., ''Çileklerde (fragaria) çiçeklenme ile fotoperiyot arasındaki ilişkiler'' ***Anadolu Tarım Bilimleri Dergisi,*** 27(2), s. 1-5, Samsun-Hatay, 2012.

Geçer, M.K., Gündoğdu, M., ve Başar, G., '' Bazı çilek çeşitlerinin Merzifon (Amasya) ekolojisindeki verim durumlarının tespiti'' ***Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi 8(2),*** s.11-15, 2018**.**

Gehrmann, H., '' Growth, yield and fruit quality of strawberries as affected by water supply'', ***International Symposium on Water Relations in Fruit Crops,*** 171, s. 4-12, 1985.

Kaman, H., Gübbük, H., Tezcan, A., Can, M. Ve Özbek, Ö., ''Water-yield relationship of greenhouse -grown strawberry under limited irrigation'' ***Notulae Botanicae Horti Agrobotanici Cluj- Napoca,*** 51(2), s. 5-14, 2023.

Kaman, H., Gübbük, H., Tezcan, A., Can, M. Ve Özbek, Ö., '' Yield and quality of strawberry under deficit irrigation and fixed partial root drying regimes'' ***Pak. J. Agri. Sci.,*** 60(4), s. 555-563,2023.

Krüger, E., Josuttis, M., Nestby, R., Toldam-Andersen, T.B., Carlen, C., ve Mezzetti, B., ''Influence of growing conditions at different latitudes of Europe on strawberry growth performance, yield and quality'' ***Journal of Berry Researc(2),*** s. 143-157,2012.

Liu, F., Savic, S., Jensen, C.R., Shahnazari, A., Jacobsen, S.E., Stikic, R., Andersen, M.N., Water relations and yield of lysimeter-grown strawberries under limited irrigation, ***Scientia Horticulture***, 111,2, s.128-132, 2007.

Özbahçali, G., Aslantaş, R., Bazı çilek çeşitleri (fragaria x ananassa duch.)'nın erzurum ekolojisindeki performanslarının belirlenmesi, Yüksek Lisans Tezi***, Atatürk Üniversitesi Fen Bilimleri Enstitüsü***, Erzurum, 2014.

Paydaş Kargı, S., Sarıdaş, M.A., ''Modern çilek yetiştiriciliği'' ***Tarım Gündem Dergisi,*** 2(8), s.36-41, 2012.

Sarwari, A. Q., Çilekte farklı sulama düzeyleri ve absisik asit uygulamalarının verim ve morfo-fizyoloji üzerine etkileri, Yüksek Lisans Tezi, ***Çukurova Üniversitesi Fen Bilimleri Enstitüsü,*** Adana, s. 3-78, 2020.

Save, R., Penuclas, J., Maria, O., ve Serrano, L., ''Changes in leaf osmotic and elastic properties and canopy structure of strawberry under mild water stress'' ***HortScience 28(9),*** s. 925–927, 1993.

Şahiner, Y., Çilekte farklı sulama düzeyleri ile malç uygulamalarının verim, pomolojik, morfolojik, fizyolojik ve biyokimyasal özellikler üzerine etkileri, Yüksek Lisans Tezi, ***Çukurova Üniversitesi Fen Bilimleri Enstitüsü,*** Adana**,** s. 58-60, 2019.

Yuan, B.Z., Sun, J., ve Nishiyama, S. '' Effect of drip irrigation on strawberrygrowth and yield inside a plastic greenhouse'' **Biosyst. Eng,**87: 237–245, 2004.

The Causes and Effects of Climate Change on Decreasing Food Production in Africa

Maliha Afreen[1*], İlknur Uçak[2], M. Cüneyt Bağdatli[3]

[1]University of Veterinary and Animal Science, Lahore, Pakistan
[2]Nigde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Department of Animal Production and Technologies , Nigde, Turkiye
[3]Nigde Ömer Halisdemir University, Faculty of Architecture, Department of City and Regional Planning, Nigde, Turkiye
[*]Corresponding Author e mail: malihaafreen120@gmail.com

Abstract

Climate change becomes a major issue universally because of global warming which both are interchangeable. Global warming occurs because of pollution, deforestation and greenhouse gas emissions leading to climate change like higher temperatures, drought, floods and changing rain fall patterns. In this article we discussed about causes of climate change in Africa and their effects on food production in African countries. Extreme droughts lead towards the drying up of soil, which is not a suitable condition for agricultural crops, consequently it becomes a major reason for food insecurity. Higher temperatures create more pests' diseases in crops and livestock which also leads towards food insecurities because of loss in crops and livestock. These natural food losses also affect rural livelihoods. Fisheries also effected because of rising sea level temperatures and floods which is also a major factor of food insecurity in African region. Many waters borne diseases also spread into foods and humans due to floods which cause disturbance of food chain and human capacity to get enough nutrients from available foods. Consequently, there should be proper management of climate changes and food availability on government level to overcome the problems of food insecurity.

Keywords: *Climate change, Global warming, Agriculture, Food production, Livestock*

Introduction

Climate change is one of the biggest threats to global agricultural growth. Food production and rural livelihoods are under further strain due to the continent's weather systems' growing unpredictability and irregularity. It also has a substantial financial impact on agriculture. In many regions of the world, particularly Africa, the problems of climate change and how it affects food production are becoming more widely acknowledged. Africa is the continent extremely sensitive and most at risk from climate change, according to several research (World Bank, 2016; Liliana, 2005; Vogel, 2000; Bwalya, 2013); IPCC, 2007).

The 21st-century environmental and human problem has been attributed to climate change. Most experts, studying the possible effects of climate change, which impacted a large portion of Africa's population including rising sea levels, altered rainfall patterns, greater temperatures, and increasing climatic unpredictability. These effects of climate change are real and have potential, to affect many facets of daily life. In many regions of sub-Saharan Africa, several climate models show that agricultural food production are expected to suffer due to climate change (Al et al., 2008). One of the biggest environmental, social, and economic threats facing Africa is climate change, which is already occurring as evidenced by rising temperatures, soil drying up, increased pest and disease pressure, changes in areas that are suitable for raising crops and livestock, increased desertification in the Sahara region, floods, deforestation, and erosion (UNFCCC, 2006).

Impact of climate change on African agriculture

The 2007 study from the Intergovernmental Panel on Climate Change offers a thorough analysis of the anticipated impacts of climate change on African agriculture. Due to the combined strains of inadequate infrastructure, poverty, and governance, it predicts that Africa would be the continent most vulnerable to climate change worldwide. This century, temperatures are predicted to rise by 1.5–4ºC. Crop revenue is predicted to decline by as much as 90% by 2100, while yield reduction projections indicate a 50% decrease. Parts of the Sahara are predicted to see agricultural losses of 2-7% of GDP by 2100, whereas Western and Central Africa and Northern and Southern Africa are predicted to experience 2-4% and 0.4-1.3% losses, respectively. Sea temperature changes will have a particularly negative impact on fisheries, perhaps reducing production by 50–60%.

According to Africa's Population Emergency (2010), the population of Sub-Saharan Africa is predicted to grow from 700 million in 2007 to 1100 million in 2030 and 1500 million by 2050, with a growing urbanization trend.

Climate change and food security in Africa

Rural and pastoralist populations are at risk owing to the reduction of agricultural yields, crop failures, and livestock losses brought on by severe and protracted droughts, floods, deforestation, overgrazing, and fuelwood collection that has degraded the soil. Recurrent droughts have severely affected pastoralist areas on the border between Ethiopia, Kenya, and Somalia. The loss of livestock has caused a crisis for about 11 million people who depend on livestock for their livelihoods, and it has also led to a mass evacuation of pastoralists from drought-affected areas (IPS, 2010).

One in four households in sub-Saharan Africa lack access to enough food, according to the United Nations Development Report (United Nations, 2012). Southern Africa is particularly vulnerable to climate change, according to the IPCC (2007), and the effects might be severe, affecting many people's livelihoods. According to the IPCC (2007), climate change would cause sub-Saharan Africa's agricultural productivity to drop from 21% to 9% by 2080. According to the analysis, precipitation temperatures that rise might potentially cut stable food output by as much as 50%.

According to Rowhani et al. (2011), Tanzania's average output of rice, sorghum, and maize would decrease by 13%, 8.8%, and 7.6%, respectively, by 2050 due to the predicted 2°C increase. According to Knueppel et al. (2010), Tanzania's high levels of food insecurity are closely related to lower educational attainment. According to research by Tesso et al. (2012), Ethiopia's food production is severely hampered by climate change, with yearly production losses resulting from climatic variability rising sharply year over year. According to a 2009 assessment by the European Commission, climate change in Africa would result in lower agricultural yields, which will raise food prices and compel people to alter their patterns of production and consumption. Food security will be severely impacted by global warming, according to Schmidhuber & Tubiello (2007), who predict that between 5 and 170 million people would be in danger of famine by 2080. According to Hendriks (2005), food insecurity affects between 58% and 73% of families in South Africa, despite the country's overall food security.

Causes and effects of climate Change

Global warming and climate change are frequently used synonymously (Manstrandrea & Schneider, 2009). However, in scientific publications, climate change encompasses both global warming and all other effects of rising greenhouse gas concentrations, whereas global warming refers to rises in surface temperature. Any change in the climate over time, whether brought on by human activity or natural variability, is referred to as climate change by the Intergovernmental Panel on Climate Change (IPCC, 2001). Deforestation, ozone layer depletion, rising CO_2 and greenhouse gas emissions into the atmosphere are some of the causes of climate change (Syrquin, 2008; Manstrandrea & Schneider, 2009; Whitfield et al., 1998). Natural activities including animal respiration, volcanic eruptions, and the burning or decomposition of plants and other organic things all release carbon dioxide into the atmosphere. CO_2 is released into the atmosphere by human activities such burning solid waste, wood products, and fossil fuels to heat homes, power cars, and provide electricity (Paehler, 2007). Global warming has made droughts more severe, which reduced the amount of arable land that is available. A reduction in arable land would result in a lack of food security for many rural households who rely heavily on subsistence farming for their livelihood. Between 5 and 170 million more people are predicted to be in danger of hunger by 2080 because of global warming, which would have a substantial detrimental impact on food security (Statistical Review of World Energy, 2016).

The availability of water has a significant impact on agriculture. According to Rosenzweig & Hillel (1995), climate change would alter runoff, evaporation, rainfall, and moisture storage. Droughts began to occur in parts of tropical and subtropical Africa in the 1970s (Paehler, 2007; Syrquin, 2008). Droughts in tropical and subtropical Africa are predicted by the World Bank Group (1998) to become longer and more severe. The requirement for appropriate crop management has increased because of climate change, which causes water to escape from the soil more quickly and causes the soil to dry up quickly between rains (Southworth et al., 2000, 2002). Reduced soil productivity, food supply, and water resources may result from climate change-induced increases in the severity of droughts, floods, and shifting growing seasons (Luo et al., 1999; SWCS, 2003). In turn, this will represent suffering and mortality in the ecosystems of plants and animals.

According to the IPCC (2001), the global surface air temperature is expected to increase from 1.4 to 5.8 degrees Celsius by the year 2100 in comparison to 1990. Over the latter two decades of the 20th century, Nigeria's mean annual temperature increased by an average of 0.4 degrees Celsius in different regions of the nation (FME, 2003). Numerous areas, including agriculture, forestry, fisheries, biodiversity, water, and health, would be impacted by such changes. Conditions for the spread of illnesses and insect pests are more favorable in warmer temperatures.

Changes in wind patterns can affect the transmission of fungus and bacteria that cause crop diseases as well as wind-borne pests. In most African locations, economically significant pests and illnesses may predispose livestock to greater incidences of heat stress, increased disease transmission, and potential resistance to disease management efforts. Many forms of stored food would be more susceptible to bacterial and mold development in warmer, more humid environments, which would accelerate food spoiling and pose some toxicological health risks. Furthermore, the food chain and people's physiological ability to get the nutrients they need from their diet may be impacted by the rise in water-borne illnesses in flood-prone areas, modifications to the vectors of climate-responsive pests and illnesses, and the development of new diseases (Manstrandrea & Schneider, 2009).

Conclusion and Suggestions

Investing in technology intervention is necessary to address the vulnerabilities and weaknesses in food systems as well as to prevent and manage climate hazards to food security. From agricultural production to food distribution and consumption, climate change poses a serious threat to food security in African nations. Therefore, an integrated policy strategy is required to alleviate these hazards and safeguard cattle, water supplies, and arable land from global warming. More assistance is also required for small-scale rural farmers to boost agricultural output, especially at the domestic level.

References

Africa's population emergency, (2010 March). http://www. the daily green. com/environmental - news/latest/africa-population-47010905

Al, W., Orking, G., & Clima, O. (2008). Climate change and food security: a framework document. FAO Rome, 3.

Bwalya, M. (2013). Comprehensive Africa Agriculture Development Programme (CAADP) to reduce food security 0 emergencies in Africa. Johannesburg: NEPAD Planning and Coordinating Agency.

European Commission, (2009). Europe Aid Co-operation Office. Food security: understanding and meeting the challenge of poverty. Publications Office of the European Union.

Federal Ministry of Environment, (2003). Nigeria's First National Communication: Under the United Nations Framework Convention on Climate Change. Ministry of Environment of the Federal Republic of Nigeria.

Hendriks, S. L. (2005). The challenges facing empirical estimation of household food (in) security in South Africa. Development Southern Africa, 22(1), 103-123. https://doi. org/10.1080/03768350500044651

Intergovernmental Panel on Climate Change (IPCC), (2007). Intergovernmental panel on climate change fourth assessment report, Cambridge University Press, Cambridge, UK.

IPCC TAR WG1, (2001). The report Climate Change 2001: The Scientific Basis. In Houghton, J. T., Ding, Y.,Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K. & Johnson, C. A. (Eds.), Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.Cambridge: University Press, ISBN 0-521-80767-0. IPS (Inter Press Service NewsAgency), (2010, July 26) Climate change and diminishing fish stocks, http.www.ipsnews.net/.

Knueppel, D., Demment, M., & Kaiser, L. (2010). Validation of the household food insecurity access scale in rural Tanzania. Public health nutrition, 13(3), 360-367. https://doi.org/10.1017/S1368980009991121

Liliana, H. (2005). The food gaps: The impacts of climate change on food production: A 2020 perspective. Universal Ecological Fund, Alexandria, VA, USA.

Luo, Y., Reynolds, J., Wang, Y., & Wolfe, D. (1999). A search for predictive understanding of plant responses to elevated CO_2. Global Change Biology, 5(2), 143-156.

Manstrandrea, M. D., & Schneider, S. H. (2009). Global Warming. Microsoft® Encarta® Online Encyclopedia.

Paehler, K. (2007). Nigeria in the dilemma of climate change. Country report. Konrad Adenauer Publications, Nigeria Office. Also available at http//www.kas.de/proj/home/pub/33/2/Document_id-11468/index.html

Rosenzweig, C., & Hillel, D. (1995). Potential impacts of climate change on agriculture and food supply. Consequences, 1(2), 23-32.

Rowhani, P., Lobell, D. B., Linderman, M., & Raman Kutty, N. (2011). Climate variability and crop production in Tanzania. Agricultural and forest meteorology, 151(4), 449-460. https://doi. org/10.1016/j.agrformet.2010.12.002

Schmidhuber, J., & Tubiello, F. N. (2007). Global food security under climate change. Proceedings of the National Academy of sciences, 104(50), 19703-19708. https://doi.org/10.1073/pnas.0701976104

Soil and Water Conservation Society (SWCS) (2003). Conservation implications of climate change: soil runoff from croplands. SWCS: Ankey, Iowa, USA. Also available at http:/ www.swcs.org/docs/climate%20change-final.pdf

Southworth, J., Pfeifer, R. A., & Habeck, M. (2002). Crop modeling results under climate change for the upper Midwest USA. In Effects of Climate Change and Variability on Agricultural Production Systems (pp. 127- 157).

Boston, MA: Springer US.

Southworth, J., Randolph, J. C., Habeck, M., Doering, O. C., Pfeifer, R. A., Rao, D. G., & Johnston, J. J. (2000). Consequences of future climate change and changing climate variability on maize yields in the midwestern United States. Agriculture, Ecosystems & Environment, 82(1-3), 139-158.

Statistical Review of World Energy, (2016). BP viewed 28 November 2017. http:// www.bp.com/en/global/corporate /energy-economics/ statistical- review- of- world energy. html

Syrquin, A. (2008). EU Commission discusses soil degradation and climate change. Jerusalem Post. http:/www.jpost.com/servlet/satellite? cid

Tesso, G., Emana, B., & Ketema, M. (2012). A time series analysis of climate variability and its impacts on food production in North Shewa zone in Ethiopia. African Crop Science Journal, 20, 261-274.

The World Bank Group, (1998). Climate change and sub-Saharan Africa: issues and opportunities. Africa Region Findings No. 120. Also available at http:/www.worldbank.org/afr/findinds/ English/find120.htm

UNFCCC (2006, November 15). Former UN Secretary-General Kofi Annan, addressing the Twelfth Conference of the Parties to the UNFCCC, Nairobi, Kenya.

Vogel, C. (2000). Usable science: An assessment of long-term seasonal forecasts amongst farmers in rural areas of South Africa. South African Geographical Journal, 82(2), 107-116. https://doi.org/10.1080/03736245.2000.9713700

Whitfield, C. P., Davison, A. W., & Ashenden, T. W. (1998). The effects of nutrient limitation on the response of Plantago major to ozone. New Phytologist, 140(2), 219-230.

World Bank. (2016). Arable land (hectares per person). viewed 28 November 2017, from http://data.worldbank.org/indicator/AG.LND.ARBL.HA.PC

Farklı Ön Uygulama Yapılan Kocadarı (*Sorghum Vulgare* L.) Tohumlarının Kontrollü koşullarda Çimlenme ve İlk Gelişme Dönemlerinin İncelenmesi

Aslı Sözeri[1] Saime Ünver İkincikarakaya[2], Leyla İdikut[1], Kazım Emre Göktaş[1]

[1] Kahramanmaraş Sütçü İmam Üniversite, Ziraat Fakültesi, Tarla Bitkiler Bölüm, Kahramanmaraş, TÜRKİYE

[2] Ankara Üniversitesi, Ziraat Fakültesi, Tarla Bitkiler Bölüm, Ankara, TÜRKİYE

Corresponding Author: Aslı SÖZERİ

Aslı SÖZERİ; asli-yorgun38@hotmail.com; ORCID No: **0009-0008-9134-7814**

Saime İKİNCİKARAKAYA; Saime.Unver@agri.ankara.edu.tr; ORCID No: **0000-0001-8561-9002**

Leyla İDİKUT;leylaidikut@gmail.com; ORCID No: **0000-0002-0685-7158**

Kazım Emre GÖKTAŞ;kazimemre011@gmail.com; ORCID No: **0000-0001-5723-2054**

Özet

Araştırmada, Kocadarı tohumlarına, PEG (%20), Mannitol (%6), Sorbitol (%10) ve saf su ve kontrol olmak üzere beş farlı ön uygulama yapılarak, çimlenme kriterleri ve fide gelişiminin incelenmesi amaçlanmıştır. Çalışma, Ankara Üniversitesi Ziraat Fakültesi Tarla Bitkileri Bölümü laboratuvarında, tesadüf parselleri deneme desenine göre dört tekerrürlü olarak 2023 yılında yürütülmüştür. Tohumlar 24 saat boyunca uygulama ortamlarında bekletilmesinden sonra, 24 saat da kurutma kâğıtları üzerinde kurutulup kontrollü koşullarda çimlenmeye bırakılmıştır. Laboratuvar koşullarında çimlenmesi izlenen tohumların çimlenme hızı ve gücü, sürgün ve kökçük uzunluğu, sürgün yaş ve kuru ağırlığı, kökçük yaş ve kuru ağırlığı değerleri kaydedilmiştir. Kocadarı tohumların kontrollü laboratuvar koşullarında çimlendirilmesinde incelenen özelliklerin ön çimlendirme (priming uygulaması) yönünden önemli farklılıklar oluşturduğu kaydedilmiştir. Laboratuvar sonuçlarına göre çimlenme hızı ve çimlenme gücü olarak priming uygulanan tohumların kontrole oranla daha belirgin bir artış gösterdiği, incelenen özelliklerde PEG %20 ve saf su uygulamaların olumlu etkide bulunduğu belirlenmiştir.

Anahtar Kelimeler: *Sorghum vulgare* L., Priming, PEG, Mannitol, Sorbitol

Investigation of Germination and Initial Development Periods of Sorghum (*Sorghum Vulgare* L.) Seeds with Different Pretreatments under Controlled Conditions

Abstract

The study aimed to investigate germination criteria and seedling development by applying five different pretreatments to sorghum seeds: PEG (20%), Mannitol (6%), Sorbitol (10%), distilled water, and a control. The study was conducted in 2023 at the laboratory of the Field Crops Department of the Faculty of Agriculture at Ankara University, using a randomized plot design with four replications. After soaking the seeds in the treatment media for 24 hours, they were dried on blotting paper for another 24 hours and allowed to germinate under controlled conditions. Germination rate and strength, shoot and radicle length, shoot fresh and dry weight, and radicle fresh and dry weight of the seeds monitored under laboratory conditions were recorded. It was noted that the characteristics examined in the germination of millet seeds under controlled laboratory conditions produced significant differences in terms of priming treatment. According to laboratory results, it was determined that primed seeds showed a more significant increase in germination speed and germination power compared to the control, and that PEG 20% and distilled water applications had a positive effect on the examined traits.

Key Words: *Sorghum vulgare* L.*,* priming, PEG, mannitol, sorbitol

Giriş

Doğu Afrika kökenli olduğu bilinen kocadarı, M.Ö dönemlerde Mezopotamya ve Hindistan'da yetiştirilen insanlık tarihinde ilk kültüre alınan bitkilerdendir. Uygun kök yapıları sayesinde etkin su emebilme gücüne sahiptir. Su isteği olarak mısırla benzerlik gösterir ancak mısıra kıyasla uzun süreli kuraklık dönemlerinde uykuya geçme yeteneği bulunmaktadır (Undersander ve ark. 1990). Ülkemiz şartlarında daha çok ikinci ürün olarak tarımı yapılan kocadarılar, kurak ve yarı kurak bölgelerde temel gıdalar arasında yer almaktadır. Yüksek verimli olmalarının dışında kaba yem olarak temin edilmeleri, kolay ulaşılabilirlik ve düşük maliyetli olması, öne çıkan faktörler arasındadır. Sıcak iklim koşullarında yayılım gösteren darılar, dünya üzerinde oldukça fazla ekim alanına sahiptir. Ekimi takiben yaklaşık 60-90 günlük periyotta tohum olgunluğuna ulaşırlar. Ortalama olarak 100 kg/da tohum verimi ile 100-250 kg/da arasında kuru ot verimi elde edilmektedir (Baytekin ve ark. 1995). Kuraklığın her geçen gün artması, kocadarı bitkisinin tarımının yaygınlaşmasını teşvik edecektir. Tarımda yetiştirilen bitkilerin yaygınlaşmasında yetişme süresinin kısa olması, tarımının mekanize olması, çimlenmenin kısa ve homojen olması önem arz etmektedir. Tohuma yapılan ön uygulamalar kuraklık tolerans mekanizmasını teşvik ederek son derece etkin olarak kullanılabilecek, fizyolojik yaklaşımları içine alan, pratik, kolay uygulanabilir ve düşük maliyetli uygulamalardır. Tohumda yaşlanma biyolojik değeri düşürerek stres şartlarına dayanıklılık ve çimlenme oranını azaltmaktadır. Priming uygulaması ise tohumda yaşlanma kaynaklı olumsuz etkileri hafifletmektedir. Dormant tohumlar, uygun koşullar sağlanmadığında çimlenemezken, dormant olmayan tohumlar ise uygun şartlar oluştuğunda çimlenme imkanı bulabilmektedir. Bazı bitki türleri için su yeterli olurken, bazıları için ışık, toprak koşulları ve sıcaklıktaki dalgalanmalar gibi ek faktörlerin de bulunması gerekmektedir. Bu faktörlerin eksik olması durumunda çimlenme engellenmekte ve tohumlar zorunlu dinlenmeye girmektedir (Elkoca, 2007). Ekim öncesi tohuma uygulanan priming uygulanmasının, üretici koşullarında uygulanabilirlik olarak sınırlı olduğunu ve ıslak tohumların ekiminde ortaya çıkan zorluklar sebebiyle pratikte pek mümkün olmadığı vurgulanmıştır (Girolamo ve Barbanti (2012). Ön çimlenmeden sonra tohumların kurutulması bekletilmesi, çimlenme ve çıkışa katkı sağlamaktadır. Dört farklı mercimek hattına uygulanan 10 farklı kurşun çözeltisinin 15°C'de sıcaklıkta laboratuvar ortamında, çimlenme süresi, çimlenme yüzdesi, plumula uzunluğu, radikül uzunluğu ve canlılık indeksi artan kurşun konsantrasyonu sebebiyle çimlenme süresi dışında tüm parametrelerde gözle görülür bir azalma gözlemlendiği kaydedilmiştir (Çokkızgın 2010). Bu çalışmada, kocadarı tohumlarının çimlenmesinin erken olması ve homojen çıkışın sağlanması amacıyla, farklı kimyasallarla ön çimlendirilmesi yapılan tohumların kontrollü koşullarda çimlenme ve fide gelişim dönemleri incelenmiştir.

Materyal Ve Metot

Deneme, 2024 yılında Ankara Üniversitesi Ziraat Fakültesi Tarla Bitkileri Bölümü'nün laboratuvarında gerçekleştirilmiştir. Bitki materyali olarak kocadarı (Sorghum vulgare L.) tohumları kullanılmıştır. Çalışmada kontrol, saf su, PEG (%20), sorbitol (%10) ve mannitol (%6), ve saf su olarak beş farklı ön çimlenme ortamı kullanılmıştır. Ön çimlenmede 24 saat bekletildikten sonra üç kez yıkanarak, 24 saat boyunca havlu kâğıtlar üzerinde kurutma işlemi gerçekleştirilmiştir. Kurutma işleminden sonra tohumlar 20x20 cm boyutundaki çimlenme kağıdı üzerine 20 şer tohum yerleştirilerek 2-3 ml saf su ilave edilerek, şeffaf plastik kaplara yerleştirilmiştir. Nem kaybını önleme amacıyla ağzı kilitli torbalar içeresine yerleştirilerek sıcaklığı ±1 ºC hassasiyetinde çalışan, tohum çimlendirmeye uygun %70 nem içeren çimlendirme kabinlerine yerleştirilip, standart çimlenme sıcaklığı 25ºC'ye ayarlanarak çimlenmeye bırakılmıştır. Deneme dört tekerrürlü olarak tesadüf parselleri deneme deseninde planlanmıştır. Çimlenme ortamında çıkış gözlenen tohumların çimlenme hızı ve çimlenme gücü, sürgün uzunluğu, kökçük uzunluğu, sürgün yaş ağırlığı, kökçük yaş ağırlığı, sürgün kuru ağırlığı, kökçük kuru ağırlığı gibi özellikler için gözlem kayıtları tutulmuştur. Araştırmada incelenen özelliklerin istatistik analizinde SAS JMP 13 veri analiz sistemi kullanılmıştır. Ortalamaların gruplandırmasında Duncan testi uygulanmıştır.

Bulgular Ve Tartışma

Kocadarı (*Sorghum vulgare* L.) tohumları laboratuvar koşullarında farklı ön uygulama yapılarak kurutulan tohumlar laboratuvar koşullarında çimlendirilmesi yapılmıştır. Priming uygulaması yapılan tohumların, çimlenme özellikleri üzerine olan etkileri incelenerek elde edilen veriler alt başlıklar halinde sıralanarak yorum ve tartışması yapılmıştır.

Çimlenme Hızı (%)

Çimlendirme amacı ile kullanılan tohumlar günlük olarak sayılmıştır. ISTA kurallarına uygun olarak çimlenme hızını belirlemek amacı ile 5. gün yapılan sayımlarda çimlenen tohumlar gözlemlenerek çimlenme hızı (%)olarak kaydedilmiştir. Laboratuvar koşullarında çimlendirilmesi yapılan kocadarı tohumları, çimlendirme hızı yönünden priming uygulamalarına göre istatistiki olarak dört farklı grupta yer almıştır. En yüksek çimlenme hızı, PEG %20 ve saf su uygulamalarında sırasıyla %78,75 ve %77,50 olarak elde edilmiştir. Bu iki uygulama arasında istatistiksel olarak anlamlı bir farklılık bulunmamış olup diğer uygulamalar belirgin farklılıklar göstermiştir. En düşük çimlenme hızı ise %46,25 ile Mannitol %6 uygulaması sonucunda elde edilmiştir, bu uygulamayı ikinci sırada kontrol uygulaması izlemiştir (Çizelge 1). Tohuma uygulanan PEG ve bazı tuzlar kökçüğün tohum kabuğundan çıkışını engelleyerek ekim öncesi çimlenmenin ilk aşamasında gerçekleşmesini sağlar. (Heydecker ve Coolbear., 1977). Priming uygulamaları birçok bitki türünde düşük sıcaklık ve elverişli olmayan koşullarda çimlenme hızı ve oranını artırdığını ve istenilen sıklıkta fide yetiştirmeyi mümkün hale getirdiği belirtilmiştir (Zheng ve ark., 1994). Saf su, osmo-priming PEG 6000 (0. 8 Mpa) uygulamasının kontrol grubuna kıyasla çimlenme hızında gözle görülür bir fark oluşturduğu, tohumda ön çimlendirme uygulamasının osmatik stresi azaltarak erken bitki çıkışını ve tohum kaybını önleme potansiyeline sahip olduğu belirlenmiştir. Kışlık buğday tohumları ile laboratuvar ortamında gerçekleştirdikleri 10 farklı PEG uygulamasında çeşitler arasında priming süresi boyunca çimlenme oranında farklılıkların olduğu tespit edilmiştir (Giri ve Schillinger., 2003).

Çimlenme Gücü (%)

Çimlenme hızı belirlenen tohumlar çimlendirme kabininde belirli bir süre tutulmaya devam edilerek 8. gün yapılan sayımlarda elde edilen değer, çimlenme gücü yüzdesi olarak belirlenmiştir. Priming uygulaması yapılan kocadarı tohumlarının laboratuvar koşullarında çimlendirilmesinde çimlendirme gücü yönünden istatistiksel olarak birbirinden farklı dört grup oluşturmuştur. Çimlenme gücü verileri incelediğinde en yüksek çimlenme gücü %82.50 ile PEG %20 uygulamasında elde edilmiş olup ikinci sırada saf su uygulamasında elde edildiği ve istatistiki olarak aynı grupta yer aldığı belirlenmiştir. Sorbitol %10 uygulamasında %66.25 çimlenme gücü ile ikinci grubu oluşturmuştur. En düşük çimlenme gücü mannitol %6 uygulamasında %47.50 olarak kaydedilmiştir (Çizelge 1). (Zheng ve ark., 1994) tarafından, primin uygulamasının düşük sıcaklıkta ve elverişsiz koşullarda çimlenme ve çıkışı artırarak istenen bitki sayısının sağlanabileceği belirtilmiştir. (Çalık Koç ve ark., 2024) kontrolde çıkışların primin uygulamasına göre geç başladığını ifade etmişlerdir. (Tanveer ve ark., 2010), *Brahmi-Bacopa monnieri* (L.) kültürlerinin büyüme ortamlarına yüksek konsantrasyon içerikte mannitol eklenmesi durumunda kök uzunluğu ve kök dallarında artış sağladığını belirlemişlerdir. Tohumda çimlenmeyi iyileştirmek ve bitki verimini artırmak amacıyla en uygun tekniklerden biri olan çimlenme öncesi işlemler, tohumun fizyolojik gelişmesini içerir ve kontrollü koşullarda su veya diğer öncesi işlem maddelerinde bekletilerek ön çimlenme metabolizmasının başlamasını sağlar. (Rakshit ve Singh., 2018 Kırca ve Aygün., 2018).

Sürgün Uzunluğu (cm)

Priming uygulanan kocadarı tohumlarının laboratuvar ortamındaki çimlendirilmesinde en fazla sürgün uzunluğu 7.86 cm ile PEG %20 uygulamasında, en az 6.54 cm ile saf su uygulamasından elde edildiği ve istatiksel olarak birbirlerinden farklı grubu oluşturduğu kaydedilmiştir. Diğer Sorbitol %10, Mannitol % 6 ve kontrol priming uygulamasının tohumları kendi aralarında istatistiki farklılık oluşturmayıp geçiş grubunda yer almışlardır (Çizelge 1). (Çalık Koç ve ark., 2024), tarafından, mercimek tohumları polietilen glikol, sorbitol ve damıtılmış su uygulamalarında sorbitol uygulamasının çimlenme ve fide gelişimi açısından avantajlar sağladığını belirmişlerdir. (Pandolfia ve ark., 2012) Hoagland solüsyonunda büyütülmüş bezelye (*Pisum sativum*) fidelerine farklı dozda NaCl ve %25 PEG 6000'e uyguladıklarında bezelye fidelerine tuz stresine karşı NaCl uygulamasının PEG 6000 uygulamasından daha etkili olduğunu kaydetmişlerdir. Daha önceki çalışmalarda da anlaşılacağı gibi, ön uygulamaların sap uzunluğu için uygun ortam oluşturmasını pozitif etki yaptığı belirtilmiştir. En yüksek sap uzunluğunun PEG %20 uygulamasında görüldüğü ve uygulama faktörlerine göre değiştiği belirlenmiştir.

Kökçük Uzunluğu (cm)

Farklı ortamlarda primin uygulanan kocadarı tohumların kontrollü laboratuvar koşullarında çimlendirilmesinde kökçük uzunlukları en yüksek 5.05 cm ile saf su uygulamasında elde edildiği, en az ise 4.18 cm ile sorbitol %10 uygulamasından elde edildiği ve istatiksel olarak birbirlerinden farklı grupta yer aldığı tespit edilmiştir. Diğer PEG, Mannitol % 6 ve kontrol priming uygulamasının tohumları kendi aralarında istatistiki farklılık oluşturmayıp geçiş grubunda yer almışlardır. Kökçük uzunluğu bakımından uygulamalar arası farklılık 0,05 düzeyinde önemli bulunmuştur (Çizelge 1). Farklı gentotiplerde beş farklı domates üç farklı polietilen glikol 6000 kökenli kuraklık stresine tabi tutulan Monoprecas genotipinin kök uzunluğunun PEG konsantrasyonunda %3'de arttığını %6'lık konsantrasyonda azaldığını açıklamışlardır (Yadav ve ark., 2024). (Al-Ansari ve Ksiksi., 2016), tohum çimlenmesinin iyi olması kök gelişimi ve mahsul verimi de önemli etkide bulunduğunu belirtmiştir. Priming uygulaması metabolik aktiviteleri artırdığı (Iqbal ve Ashraf., 2005), mannitol eklenmesi kök dallanmasını ve kök uzamasını yol açtığını (Tanveer ve ark., 2010) belirlenmişlerdir. Daha önceki çalışmalar, farklı ön uygulamalar için uygun ortam oluşturması kök uzunluğunda artışı meydana geldiğini açıklamaktadır.

Sürgün Yaş Ağırlığı (mg)

Fidenin sürgün ve kökçükleri ayrılıp hassas terazide tartılarak sürgün ve kökçüklerin yaş ağırlıkları mg/fide olarak belirlenmiştir. Farklı priming uygulaması sonucu çimlendirilen tohumlardan en yüksek sürgün yaş ağırlığı 0.47 ile PEG %20 uygulamasından elde edilmiş olup en az ise 0.24 mg ile Mannitol %6 uygulamasından elde edildiği ve kendi aralarında istatiksel olarak önemli farklılık oluşturduğu görülmüştür. Diğer Sorbital %10, saf su ve kontrol uygulamalar istatiksel olarak önemli farklılığın olmadığı ve PEG %20 uygulamasıyla sürgün yaş ağırlığı yönünden aynı istatistiksel grupta yer almıştır (Çizelge 1). (Girolamo ve Barbanti .,2012) tohumlara priming uygulamasından sonrası kazanılan olumlu etkinin, depolama boyunca sürdürülebilmesi yönünden önemli olduğunu belirmiştir. Hurmada, düşük sürgün kümelerinin uzaması ve zayıf kök oluşumu, köklenme aşamasında başarıyı engelleyebileceği dikkate alınarak, ilave edilen farklı alkol şekerleri, sorbitol veya mannitolün köklendirme ortamına ilave edilmesinde sürgün uzamasını ve kök sistemini en iyi şekilde geri kazanılmasını sağladığını açıklamışlardır (Abd Elzaher ve ark., 2019) Priming uygulamaların tohumun gelişimin başlatması nedeniyle kök uzunluğunda katkı daha önceki çalışmalar desteklenmektedir.

Sürgün Kuru Ağırlığı(mg)

Ön uygulama yapılan kocadarı tohumlarının laboratuvar koşullarında çimlendirilmesin sürgün kuru ağırlığında en yüksek değer sırasıyla sorbitol %10, PEG %20 uygulamasında 0.23 g olarak elde edildiği ve aynı grupta yer alarak diğer uygulamalardan istatiksel farklılık oluşturduğu kaydedilmiştir. Diğer Mannitol %6, saf su, kontrol uygulamalarında sürgün kuru ağırlığı sırasıyla 19, 17, 17 mg olarak belirlenmiş ve aynı istatistiki grupta sahip olduğu tespit edilmiştir. Uygulama ortamları arasında istatistiki olarak %1 düzeyinde önemli farklılıklar saptanmıştır (Çizelge 1). (Parera ve Cantliffe., 1994) PEG, KNO3 ve mannitol uygulan pırasa tohumlarının çimlendirme zamanına kadar depolanması sonucunda, çimlendirilen tohumlar incelendiğinde mannitol ve polyethylene glycol uygulamaları potasyum nitrat ve kontrole oranla daha iyi sonuçlar verdiğini bildirmişlerdir. Parera ve Cantliffe (1994) tarafın, pırasa tohumlarının çimlendirmesinde potasyum nitrat ve kontrole uygulamalarına göre mannitol ve polyethylene glycol uygulamalarını pozitif etkisinin olduğunu ifade etmişlerdir. Daha ön yapılan çalışmalarda mannitolün abiyotik stres faktörlerinin zararını azalttığı (Yıldız ve ark., 2010), sebze üretiminde kaliteyi ve verime katkı sağladığını (Arın ve Çerençe., 2023) belirtmişlerdir.

Farklı ön uygulamaların, tohumda sap kuru ağırlığına olumlu etkisinin olduğu önceki çalışmalardan da anlaşılmaktadır. Yürütülen çalışmalar elde edilen sonuçlar daha önceki çalışmalarla desteklenmektedir.

Çizelge 1. Farklı ön uygulamalara göre incelenen özelliklere ait ortalamalar ve gruplar.

Uygulamalar	**Çimlenme Hızı****	**Çimlenme Gücü ****	**Sürgün Uzunluğu***	**Kökçük Uzunluğu***	**Sürgün Yaş Ağırlığı****	**Sürgün Kuru Ağırlığı****
PEG %20	78.75 a	82.50 a	7.86 a	4.72 ab	0.47 a	0.23 a
Sorbitol %10	63.75 c	66.25 c	5.75 ab	4.18 b	0.45 a	0.23 a
Mannitol %6	46.25 d	47.50 d	5.63 ab	4.31 ab	0.24 a	0.19 b
Saf su	77.50 a	77.50 a	6.54 ab	5.05 a	0.42 b	0.17 b
Kontrol	71.25 b	76.25 b	5.38 b	4.69 ab	0.46 a	0.17 b
Ortalamalar	67.50	70.00	6.23	4.59	0.41	0.20

**0.01düzeyinde, *0,05 düzeyinde önemli

Sonuç

Priming uygulama, tohumların çimlenme performansı üzerinde son derece etkili olan çeşitli faktörlerin etkisi ortaya koymaktadır. Uygun olmayan çevre şartları ile tohum kalitesi ve yapısından kaynaklanan çimlenme ve çıkış sırasında yaşanabilecek olumsuzlukları en az seviyeye indirilmesi, homojen fide çıkışının en kısa sürede sağlanması, güçlü fide gelişimini desteklemesi ve stres koşullarına dayanıklılığı artırılması amacıyla, ekim öncesi yapılan ön çimlendirmenin, tohumlarda daha hızlı çıkış ve çimlenme sağladığı, fide ve kök uzunlukları açısından da daha belirgin sonuçlar elde edildiği belirlenmiştir. Bu bağlamda, uygulanan

tohumlardan daha yüksek verim ve ekonomik kazanç sağlamak amacıyla saf su ile priming işlemi önerilmektedir. Tohum uygulamalarının bu türler üzerindeki çimlenme sonrası etkilerinin değerlendirilmesi, verime olan etkilerinin belirlenmesi açısından son derece önemlidir. Tohuma ön çimlendirme uygulamalarından elde edilen sonuçların daha etkili bir şekilde değerlendirileceği ve birçok bitki türüne katkı sağlayacağı, çeşitli verim unsurları üzerine çalışmaların yapılması önerilmektedir.

Araştırmacıların Katkı Oranı Beyan

Makalede yazarlar eşit katkı oranları sahiptir.

Çıkar Çatışması Beyan

Makale yazarları aralarında çıkar çatışması bulunmamaktadır.

Teşekkür

Bu çalışma Prof. Dr. Leyla İDİKUT ve Prof. Dr. Saime ÜNVER İKİNCİKARAKAYA eş danışmanlığında Aslı SÖZERİ tarafından yürütülen "Kocadarı (*Sorghum vulgare* L.) Tohumlarına Farklı Ön Uygulamalarının (Priming) İlk Gelişme Dönemindeki Etkileri" İsimli Yüksek Lisans tezi verilerinden oluşturulmuş olup Kahramanmaraş Sütçü İmam Üniversitesi Bilimsel Araştırma Projeleri birimi tarafından 2024/4-3 YLS nolu proje olarak desteklenmiş araştırmanın bir bölümünü kapsamaktadır.

Kaynakça

Abd Elzaher, M. H., Abd Elwahab, S. M., Elsharabasy, S. F., El-Dawayati M. M., Fouad, H. A. 2019. Rootıng Recovery and Chemıcal Analysıs of Date Palm Shootlets after Sorbıtol and Mannıtol Sugars Stress. *Plant Archives* 19 (2): 886-894 e-ISSN:2581-6063, ISSN:0972-5210.

Çalık Koç, G., Rezaei, F., Kahraman Ilıkkan, Ö., Bağdat, E. Ş. 2024. Effect of Seed Priming With Polyethylene Glycol, Distilled Water, And Sorbitol on Physical, Chemical Quality Parameters, and Nodule Microbiota of Lentil. *Brazilian Journal of Microbiology.* https://doi.org/10.1007/s42770-024-01456-1.

Çeçen ve ark., 2005) Çeçen, S., M. Öten ve C. Erdurmuş, 2005. Batı Akdeniz sahil kuşağında sorgum (*Sorghum bicolor* L.), sudanotu (*Sorghum sudanense* Staph.) ve mısırın (*Zea mays* L.) ikinci ürün olarak değerlendirilmesi, *Akdeniz Üniv. Zir. Fak. Derg.* 18(3):337-

Golezanik, G., Alıloo, A.A., Valızadem, M. and Moghaddam, M. 2008. *Effects of hydro and*

Heydecker, W., Coolbear, P., 1997. Seed Treatments for Improved Performance Survey Prognosis. *Seed Sci. And Tech.* 5; 353-425.

Kırca, L., & Aygün, A. (2018). Ahlat (Pyrus elaeagrifolia Pall.) tohumlarının çimlenmesi üzerine potasyum nitrat (KNO3) uygulamalarının etkisi. Uluslararası Tarım Kongresi (UTAK 2018).

Parera, C.A., and Cantliffe, D.J., 1994. Priming leek seeds to improve germination an emergence at high temperature. HortScience, 27, 1077-1079.

Rakshit, A., & Singh, H.B. (Eds.). (2018). Advances in seed priming (pp. 147-183). Singapore: Springer. https://doi.org/10.1007/978-981-13-0032-5

Tanveer, A., Khan, M., Shah, F. (2010). In vitro micropropagation of Brahmi-Bacopa monnieri (L.) Pennel-A step for conservation. Nanobiotechnica Universale, 1(2): 139-150.

Teksan, B.Ö., Kavak, S., 2016. Kadife Çiçegi ve Gül Taç Yaprakları 134Yüzüncü Yıl Üniversitesi Fen Bilimleri Enstitüsü Dergisi/ Journalof the Institute of Natural& Applied Sciences Kenanoğlu Demleme Çaylarında Ön Çimlendirme Uygulamalarının Biberde Çimlenme ve Çıkıs Üzerine Etkileri. Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi. 11(1):34-42.

Uzun, F., Aydın, I., 2004, Improving germination rate of Medicago and Trifolium species. Asian Journal of Plant Sciences, 3, 714-717

Vahedi ve ark., (2015) Vahedi, M., Kalantari, S. ve Salami, S.A. (2015). Ozmolitik ajanların somatik doku üzerindeki etkileri safranın (Crocus sativus L.) embriyogenezi. Notulae Scientia Biologicae, 7(1), 57-61.

Yadav, P. K., Bhujel, P., Bhandari, N., Sharma, S. 2024. Assessment of germination and seedling development of tomato genotypes under polyethylene glycol (PEG)-induced drought. https://doi.org/10.21203/rs.3.rs-4006037/v1

Yamaguchi, S., Kamiya, Y. (2002). Gibberellins and light-stimulated seed germination. J. Plant Growth Regul. 20, 369–376.

Zheng, G.H., Wilen, R.W., Slinkard, A.E., Gusta, L.V., 1994. Enhancement of canola seed germination and seedling emergence at low temperature by priming. Crop Science, 34: 1589-1593.

Hayvancılık Sektöründe Dijital Tarımın Kullanım Alanları ve Ekonomik Katkıları

Mutlu Bulut[1]

[1]Hayvansal Üretim ve Teknolojileri Bölümü, Tarım Bilimleri ve Teknolojileri Fakültesi, Niğde Ömer Halisdemir Üniversitesi, Niğde, Türkiye

Özet

Tarım 4.0 anlayışıyla birlikte gelişen dijital tarım uygulamaları, hayvancılık sektöründe üretim verimliliğini artıran, maliyetleri düşüren ve sürdürülebilirliği destekleyen yenilikçi çözümler sunmaktadır. Bu çalışmada, hayvancılık işletmelerinde kullanılan dijital teknolojilerin başlıca uygulama alanları ve bunların ekonomik katkıları incelenmiştir. Sensör tabanlı hayvan izleme sistemleri, otomatik yemleme ve sağım robotları, akıllı sürü yönetim yazılımları, nesnelerin interneti (IoT) destekli çevresel kontrol sistemleri ve yapay zekâ tabanlı verim tahmin modelleri başlıca teknolojik yenilikler arasında öne çıkmaktadır. Bu uygulamalar sayesinde hayvan refahının artırılması, hastalıkların erken teşhisi, yem ve enerji kullanımında tasarruf sağlanması ve üretim verimliliğinin yükselmesi mümkün olmaktadır. Çalışmada ayrıca, dijital tarım uygulamalarının işletme kârlılığına, kaynak kullanım etkinliğine ve gıda güvenliğine olan katkıları değerlendirilmektedir. Bulgular, dijital teknolojilerin hayvancılık sektöründe rekabet gücünü artırarak kırsal kalkınmaya önemli katkılar sunduğunu ortaya koymaktadır. Bununla birlikte, yüksek yatırım maliyetleri ve dijital okuryazarlık eksikliği gibi sınırlılıkların aşılması için kamu destekleri ve yayım faaliyetlerinin önem taşıdığı vurgulanmaktadır.

Anahtar Kelimeler: *Dijital Tarım, Hayvancılık, Ekonomik Katkı, Sürdürülebilirlik, Tarım 4.0*

Digital Agriculture Applications in the Livestock Sector and Their Economic Contributions

Abstract

With the emergence of Agriculture 4.0, digital agriculture applications have introduced innovative solutions that enhance production efficiency, reduce costs, and support sustainability in the livestock sector. This study examines the main application areas of digital technologies in livestock farms and evaluates their economic contributions. Key technological innovations include sensor-based animal monitoring systems, automatic feeding and milking robots, smart herd management software, IoT-supported environmental control systems, and AI-based yield prediction models. These applications make it possible to improve animal welfare, enable early disease detection, save on feed and energy use, and increase production efficiency. In addition, the study assesses the contributions of digital agriculture practices to farm profitability, resource use efficiency, and food security. The findings reveal that digital technologies strengthen the competitiveness of the livestock sector while providing significant support to rural development. However, high investment costs and the lack of digital literacy remain major limitations, highlighting the importance of public support and extension activities to overcome these challenges.

Keywords: *Digital Agriculture, Livestock, Economic Contribution, Sustainability, Agriculture 4.0*

Giriş

Tarım sektörü, günümüzde küresel ölçekte karşı karşıya olduğu zorluklar nedeniyle stratejik bir dönüşüm sürecine girmiştir. Dünya nüfusunun 2050 yılına kadar yaklaşık 10 milyara ulaşacağı öngörülmekte, bu durum gıda üretimine yönelik baskıyı her geçen gün artırmaktadır (FAO, 2020). Aynı zamanda iklim değişikliğinin yol açtığı üretim belirsizlikleri, doğal kaynakların azalması, çevresel sürdürülebilirlik sorunları ve artan tüketici talepleri tarım sektörünün verimlilik ve etkinlik açısından yeniden yapılandırılmasını zorunlu kılmaktadır. Bu bağlamda, son yıllarda "Tarım 4.0" kavramı öne çıkmış ve tarımsal üretimde dijitalleşme, yenilikçi teknolojilerin kullanımı ile önemli bir paradigma değişimi başlatmıştır (Wolfert vd.., 2017).

Dijital tarım, bilgi ve iletişim teknolojileri, nesnelerin interneti (IoT), büyük veri analitiği, yapay zekâ, sensör sistemleri, robotik uygulamalar ve otomasyon çözümlerinin tarımsal üretim süreçlerine entegre edilmesi olarak tanımlanmaktadır. Bu yaklaşım, yalnızca üretim sürecinin verimliliğini artırmayı değil, aynı zamanda kaynak kullanımında etkinlik sağlanmasını, çevresel sürdürülebilirliği desteklemeyi ve gıda güvenliğini garanti altına almayı hedeflemektedir (Tzounis vd.., 2017). Özellikle hayvancılık sektörü, hem üretim ölçeği hem de kaynak bağımlılığı nedeniyle dijital tarım uygulamalarının en yoğun şekilde uygulandığı alanlardan biri haline gelmiştir. Hayvancılıkta dijitalleşme sayesinde hayvan refahının artırılması, hastalıkların erken teşhisi, sürü yönetiminde etkinlik, yem ve enerji tasarrufu sağlanması mümkün olmaktadır (Rutten vd.., 2013).

Türkiye açısından bakıldığında, hayvancılık sektörü gerek ekonomik gerekse sosyo-kültürel boyutlarıyla stratejik bir öneme sahiptir. Ülke genelinde kırsal nüfusun geçim kaynakları arasında hayvancılık önemli bir paya sahip olup, tarımsal üretim değerinin yaklaşık üçte birini oluşturmaktadır (TÜİK, 2024). Bununla birlikte sektör, artan girdi maliyetleri, iş gücü eksiklikleri, hastalık riski ve pazarlama sorunları gibi yapısal zorluklarla karşı karşıyadır. Bu sorunların aşılmasında dijital tarım teknolojilerinin yaygınlaştırılması kritik bir rol oynamaktadır. Büyük ölçekli işletmelerde sağım robotları, akıllı yemleme sistemleri ve sensör tabanlı hayvan izleme teknolojileri hızla kullanılmaya başlanırken; küçük ve orta ölçekli işletmelerde dijitalleşme düzeyi sınırlı kalmaktadır. Bu durum, dijital dönüşümün yaygınlaştırılması için altyapı yatırımlarına, finansal destek mekanizmalarına ve yayım faaliyetlerine ihtiyaç olduğunu göstermektedir (Eastwood vd.., 2019).
Dolayısıyla bu çalışma, hayvancılık sektöründe dijital tarım uygulamalarının kullanım alanlarını ve ekonomik katkılarını kapsamlı bir şekilde ele almayı amaçlamaktadır. Çalışma, derleme yöntemiyle hazırlanmış olup, literatürde yer alan ulusal ve uluslararası araştırmalardan yararlanılarak güncel bir değerlendirme sunmaktadır. Dijital tarımın hayvancılıkta sunduğu fırsatlar, ekonomik etkiler, karşılaşılan sınırlılıklar ve gelecek için politika önerileri detaylı şekilde tartışılacaktır. Bu yönüyle çalışma, hem akademik alana katkı sağlamayı hem de karar vericilere yol gösterici öneriler sunmayı hedeflemektedir.

Dijital Tarım Teknolojilerinin Genel Çerçevesi

Dijitalleşme, 21. yüzyılda tarım sektöründe üretim ve yönetim anlayışını köklü bir biçimde dönüştüren en önemli dinamiklerden biri haline gelmiştir. Geleneksel üretim yöntemleri, artan nüfus, iklim değişikliği, kaynak kıtlığı ve gıda güvenliği gibi sorunlar karşısında yetersiz kalmakta; bu nedenle modern teknolojilerin tarımsal süreçlere entegrasyonu kaçınılmaz bir zorunluluk olarak ortaya çıkmaktadır. Bu noktada dijital tarım, yalnızca bir teknoloji seti değil, aynı zamanda üretimden pazarlamaya kadar tüm değer zincirini kapsayan bütüncül bir dönüşüm yaklaşımı olarak tanımlanmaktadır (Wolfert vd.., 2017).
Dijital tarımın en belirgin özelliği, veriye dayalı karar verme süreçlerini mümkün kılmasıdır. Üretim sürecinde kullanılan sensörler, yazılımlar ve otomasyon sistemleri sayesinde sürekli veri akışı sağlanmakta; bu veriler büyük veri analitiği ve yapay zekâ yöntemleriyle işlenerek üreticiye hızlı ve güvenilir geri bildirimler sunmaktadır. Böylelikle kaynak kullanımı daha etkin hale gelmekte, kayıplar en aza indirgenmekte ve sürdürülebilir üretim hedeflerine yaklaşılmaktadır (Kamilaris vd.., 2018). Bu yönüyle dijital tarım, yalnızca teknolojik bir yenilik değil, aynı zamanda çevresel ve ekonomik sürdürülebilirliğin de güçlü bir aracı olarak görülmektedir.
Hayvancılık sektörü, dijital tarım teknolojilerinin en hızlı benimsenen alanlarından biridir. Bunun temel nedeni, hayvansal üretimin doğrudan canlı organizmalar üzerinden gerçekleşmesi ve bu süreçlerde sürekli izleme, kontrol ve optimizasyon ihtiyacının yüksek olmasıdır. Sensör tabanlı izleme sistemleri, akıllı sürü yönetim yazılımları, otomatik yemleme ve sağım robotları gibi uygulamalar, hayvan refahını artırırken işletmelerin maliyetlerini düşürmekte ve verimliliği yükseltmektedir (Rutten vd.., 2013). Aynı zamanda, çevresel koşulların kontrolü ve izlenebilirlik sistemleri, hem ürün kalitesi hem de gıda güvenliği açısından stratejik önem taşımaktadır.

Dijital tarımın küresel ölçekte hızlı bir gelişim göstermesine rağmen, teknolojilerin benimsenme düzeyi ülkeler ve işletme ölçekleri arasında farklılık göstermektedir. Gelişmiş ülkelerde dijital çözümler daha yaygın kullanılırken, gelişmekte olan ülkelerde maliyet, altyapı ve dijital okuryazarlık eksiklikleri nedeniyle adaptasyon sınırlı kalmaktadır (Eastwood vd.., 2019). Türkiye'de özellikle büyük ölçekli süt sığırcılığı işletmeleri dijital teknolojilere yatırım yapmaya başlamış olsa da küçük ve orta ölçekli işletmelerde bu dönüşüm oldukça yavaş ilerlemektedir. Bu nedenle dijital tarımın sunduğu fırsatların yaygınlaştırılması için finansal teşvikler, eğitim programları ve altyapı yatırımları kritik bir ihtiyaç olarak öne çıkmaktadır.

Sensör Teknolojileri

Sensörler, dijital tarımın en temel bileşenlerinden biridir. Hayvancılıkta kullanılan biyometrik, davranışsal ve çevresel sensörler sayesinde hayvanların sağlık durumları, yem ve su tüketimleri, hareketlilik düzeyleri ve çevresel koşullar sürekli olarak izlenebilmektedir. Örneğin, süt sığırlarında kullanılan boyun veya ayak bileklerine takılan sensörler aracılığıyla hayvanın geviş getirme süresi, yürüme mesafesi ve davranış değişimleri anlık olarak takip edilebilmekte, bu veriler hastalıkların erken teşhisinde önemli rol oynamaktadır (Caja vd., 2016). Bu sayede veteriner müdahale maliyetleri düşerken, hayvan refahı ve üretim verimliliği artmaktadır.
Sensör teknolojilerinin hayvancılık sektöründeki en önemli katkılarından biri, toplanan verilerin işletme yönetiminde kullanılabilir bilgiye dönüştürülmesidir. Örneğin, kızgınlık döneminde hayvanların hareketliliğinin artması pedometre veya ivmeölçer sensörlerle tespit edilerek döl verimliliğinin artırılmasına katkı sağlamaktadır. Benzer şekilde, süt sığırlarında geviş getirme sürelerindeki düşüş, yemleme sorunlarının veya sindirim rahatsızlıklarının erken belirtisi olarak değerlendirilebilmektedir. Bu verilerin dijital sürü yönetim yazılımlarına aktarılması sayesinde hem hayvan refahı hem de ekonomik performans açısından önemli kazanımlar elde edilmektedir (Borchers ve Bewley, 2015). Ayrıca, sensör teknolojilerinin uzun vadede iş gücü maliyetlerini

azaltması, veteriner hizmetlerine olan ihtiyacı düşürmesi ve üretim kayıplarını önlemesi, yatırımın geri dönüşünü hızlandıran kritik avantajlar arasında yer almaktadır.

Nesnelerin İnterneti (IoT)

IoT, çiftlikte bulunan farklı sistemlerin birbiriyle iletişim kurmasını sağlayarak bütüncül bir yönetim ağı oluşturmaktadır. Yemleme robotları, sağım makineleri, çevresel sensörler ve hayvan takip cihazları internet üzerinden entegre edilerek merkezi bir sistemden yönetilebilmektedir (Tzounis vd., 2017). Bu bütünleşik yapı, üreticilere operasyonel süreçleri eş zamanlı izleme ve gerektiğinde müdahale etme olanağı tanımaktadır. IoT'nin sağladığı bu entegrasyon, enerji ve iş gücü tasarrufu sağlamakta, ayrıca gıda güvenliği açısından ürünlerin izlenebilirliğini kolaylaştırmaktadır.

Hayvancılıkta IoT uygulamaları yalnızca üretim sürecinin kontrolü ile sınırlı kalmamakta, aynı zamanda karar alma süreçlerini de desteklemektedir. Örneğin, akıllı yemleme sistemleri hayvanın günlük aktivite ve sağlık verilerine göre bireyselleştirilmiş yem rasyonları hazırlayabilmekte, bu da yemden yararlanma etkinliğini artırarak maliyetleri azaltmaktadır. Benzer şekilde, IoT tabanlı çevresel kontrol sistemleri, ahır içi sıcaklık, nem ve hava kalitesini otomatik olarak düzenleyerek hem hayvan refahını yükseltmekte hem de verim kayıplarını önlemektedir (Liakos vd., 2018). Ayrıca IoT destekli izlenebilirlik çözümleri, tüketicilerin gıda güvenliği konusundaki taleplerine yanıt vererek ürünlerin pazarda daha yüksek değer bulmasını sağlamaktadır. Dolayısıyla IoT, yalnızca operasyonel verimliliği değil, aynı zamanda piyasa rekabetçiliğini de güçlendiren stratejik bir teknoloji olarak değerlendirilmektedir.

Yapay Zekâ ve Büyük Veri Analitiği

Dijital tarımda sensörler, makineler ve yönetim sistemleri tarafından toplanan veriler büyük miktarlara ulaşmaktadır. Bu verilerin işlenmesi ve anlamlı hale getirilmesi için yapay zekâ (YZ) ve büyük veri analitiği kullanılmaktadır. Hayvancılık işletmelerinde YZ tabanlı algoritmalar, süt verimi tahmini, yem tüketimi optimizasyonu, üreme takibi ve hastalık risk analizi gibi alanlarda uygulanmaktadır (Kamilaris vd., 2018). Örneğin, YZ tabanlı modeller sayesinde mastitis gibi ekonomik açıdan büyük kayıplara neden olan hastalıklar erken teşhis edilebilmekte, bu da hem maliyetleri düşürmekte hem de verim kayıplarını azaltmaktadır.

Yapay zekâ ve büyük veri analitiği, özellikle sürü yönetiminde karar alma süreçlerini optimize etme kapasitesiyle öne çıkmaktadır. Örneğin, makine öğrenmesi algoritmaları ile hayvanların süt verim eğilimleri tahmin edilerek, yemleme programları bu öngörülere göre uyarlanabilmekte ve böylece yemden elde edilen verimlilik en üst düzeye çıkarılmaktadır (García vd., 2020). Benzer şekilde, görüntü işleme teknikleri kullanılarak hayvanların davranış kalıpları analiz edilmekte, stres veya rahatsızlık durumları erken dönemde tespit edilebilmektedir (Bhuiyan ve Wree (2023). Bu tür uygulamalar, üreticilere yalnızca operasyonel kolaylık sağlamamakta; aynı zamanda hastalık kaynaklı ekonomik kayıpları azaltmakta ve hayvan refahını artırmaktadır. Dolayısıyla yapay zekâ ve büyük veri analitiği, hayvancılık sektöründe sürdürülebilirlik ve kârlılığın artırılması açısından kritik bir teknoloji olarak değerlendirilmektedir.

Robotik ve Otomasyon Sistemleri

Robotik teknolojiler, hayvancılık işletmelerinde iş gücü verimliliğini artıran en önemli araçlardan biridir. Sağım robotları, otomatik yemleme makineleri ve gübre temizleme robotları iş gücü ihtiyacını azaltmakta, üretim hatalarını en aza indirmekte ve hayvan refahını yükseltmektedir (Rutten vd., 2013). Ayrıca otomasyon sistemleri, üretim süreçlerinin standardizasyonunu sağlayarak ürün kalitesinde süreklilik yaratmaktadır. Büyük ölçekli işletmelerde yaygınlaşan bu sistemler, uzun vadede maliyet avantajı sağlayarak yatırımın geri dönüşünü hızlandırmaktadır.

Robotik ve otomasyon uygulamalarının bir diğer önemli katkısı, hayvan-çiftçi etkileşimini yeniden şekillendirmesidir. Örneğin, sağım robotlarının kullanıldığı işletmelerde hayvanlar daha az stres altında kalmakta, bu da süt verimi ve kalitesine doğrudan olumlu yansımaktadır (Jacobs ve Siegford, 2012). Ayrıca otomatik gübre temizleme ve iklim kontrol sistemleri, çevresel hijyeni ve hava kalitesini artırarak hastalık risklerini azaltmaktadır. Literatürde, robotik sistemlerin işletme maliyetlerini %15–20 oranında düşürdüğü ve iş gücü ihtiyacını kayda değer ölçüde azalttığı rapor edilmektedir (Steeneveld vd., 2012). Bu bağlamda, robotik ve otomasyon teknolojileri yalnızca üretim sürecinde kolaylık sağlayan araçlar değil, aynı zamanda hayvan refahı ve ekonomik sürdürülebilirlik açısından stratejik yatırımlar olarak değerlendirilmektedir.

Karar Destek Sistemleri

Dijital tarımın en kritik unsurlarından biri de karar destek sistemleridir. Çeşitli sensörlerden ve kayıt sistemlerinden elde edilen veriler, yazılımlar aracılığıyla analiz edilerek üreticiye öneriler sunmaktadır. Bu sistemler, özellikle üreme yönetimi, yemleme stratejileri, sürü sağlığı ve çevresel yönetim konularında önemli katkılar sağlamaktadır (Eastwood vd., 2019). Böylece işletmeler, sezgisel karar verme yerine veriye dayalı, daha güvenilir ve ekonomik açıdan rasyonel kararlar alabilmektedir.

Karar destek sistemleri, aynı zamanda farklı veri kaynaklarını bütünleştirerek üreticiye uzun vadeli stratejik planlama imkânı sunmaktadır. Örneğin, sürü yönetim yazılımları aracılığıyla hayvanların geçmiş sağlık kayıtları, üreme verileri ve üretim performansları bir arada analiz edilmekte; bu da daha isabetli yatırım kararlarının alınmasını kolaylaştırmaktadır. Literatürde, karar destek sistemlerinin özellikle süt sığırcılığı işletmelerinde üreme başarısını artırdığı, hastalık kaynaklı verim kayıplarını azalttığı ve genel işletme kârlılığını yükselttiği belirtilmektedir (Alawneh vd., 2018). Bu yönüyle karar destek sistemleri, dijital tarım teknolojilerinin sunduğu verilerin üretici için somut ve uygulanabilir faydaya dönüşmesinde kilit bir rol üstlenmektedir.

Hayvancılıkta Dijital Tarım Uygulama Alanları

Hayvan Sağlığı ve Refahının İzlenmesi

Hayvan sağlığı ve refahı, hayvancılık sektörünün sürdürülebilirliği açısından en kritik unsurlardan biridir. Dijital tarım uygulamaları, özellikle sensör tabanlı izleme sistemleri ve giyilebilir teknolojiler aracılığıyla bu alanda önemli gelişmeler sağlamaktadır. Vücut ısısı, kalp atış hızı, aktivite düzeyi, geviş getirme süresi ve yem tüketimi gibi parametrelerin sürekli olarak izlenebilmesi, hastalıkların erken teşhisine ve önleyici tedbirlerin zamanında alınmasına imkân tanımaktadır. Bu yaklaşım, hem hayvan refahını artırmakta hem de ekonomik kayıpları azaltmaktadır.

Literatürde, sensör teknolojilerinin hayvan sağlığındaki katkılarını ortaya koyan birçok çalışma bulunmaktadır. Örneğin, Rutten vd. (2013), süt sığırlarında mastitisin erken teşhisi için sensör tabanlı sistemlerin kullanılmasının tedavi maliyetlerini %20 oranında azalttığını ve süt verim kayıplarını önemli ölçüde önlediğini rapor etmiştir. Benzer şekilde Caja vd. (2016), giyilebilir sensörlerin geviş getirme süresi ve yem tüketimindeki değişiklikleri izleyerek metabolik hastalıkların erken dönemde tespit edilmesine imkân tanıdığını ortaya koymuştur. Bu tür teknolojilerin kullanımı, veteriner müdahale sıklığını azaltarak iş gücü tasarrufu sağlamaktadır.

Hayvan refahı açısından bakıldığında, sensör tabanlı izleme sistemleri stres faktörlerinin tespiti ve önlenmesi noktasında da katkı sağlamaktadır. Örneğin, sıcaklık ve nem sensörleriyle desteklenen iklim kontrol sistemleri, hayvanların aşırı sıcaklık stresi altında kalmasını engelleyerek hem verimliliği artırmakta hem de refah standartlarını yükseltmektedir (Halachmi vd., 2019). Ayrıca bireysel izleme sayesinde hasta veya düşük performans gösteren hayvanların sürüden ayrılarak özel bakıma alınması mümkün olmakta, bu da genel sürü sağlığını iyileştirmektedir.

Sonuç olarak, dijital teknolojilerin hayvan sağlığı ve refahına yönelik uygulamaları yalnızca bireysel hayvanların yaşam kalitesini yükseltmekle kalmamakta, aynı zamanda işletmelerin ekonomik performansını da doğrudan etkilemektedir. Hastalıkların erken teşhisi, tedavi maliyetlerinin azalması, üretim kayıplarının önlenmesi ve hayvan refahı standartlarının yükselmesi; dijital tarım teknolojilerinin en önemli ekonomik ve sosyal kazanımları arasında yer almaktadır.

Yemleme ve Besleme Yönetimi

Yemleme ve besleme yönetimi, hayvancılık işletmelerinin en yüksek maliyet kalemlerinden biri olup toplam üretim giderlerinin %60'a kadarını oluşturabilmektedir. Bu nedenle yemden yararlanma etkinliğinin artırılması, hem işletme kârlılığı hem de sürdürülebilirlik açısından kritik bir öneme sahiptir. Dijital tarım teknolojileri, özellikle otomatik yemleme robotları, yem tüketim sensörleri ve akıllı yemleme yazılımları aracılığıyla bu alanda devrim niteliğinde yenilikler sunmaktadır.

Otomatik yemleme sistemleri, hayvanların beslenme ihtiyaçlarını bireysel düzeyde karşılayarak yem israfını azaltmakta ve rasyon dengesini optimize etmektedir. Caja vd. (2016) tarafından yapılan bir çalışmada, otomatik yemleme sistemlerinin yem tüketiminde daha homojen bir dağılım sağladığı ve iş gücü maliyetlerini %15 oranında azalttığı rapor edilmiştir. Benzer şekilde, iş gücü verimliliği açısından otomatik yemleme robotlarının günlük iş yükünü önemli ölçüde hafiflettiği, küçük ölçekli işletmelerde dahi ekonomik avantaj sağladığı görülmektedir.

Yapay zekâ ve büyük veri analitiğiyle desteklenen yemleme sistemleri ise yem tüketim verilerini sürekli analiz ederek hayvanların performansına göre rasyon ayarlamaları yapabilmektedir. Steeneveld vd. (2012), bu tür sistemlerin süt sığırlarında yemden yararlanma oranını artırarak süt üretiminde %5–7 arasında artış sağladığını ortaya koymuştur. Bu durum, yem maliyetlerinin düşürülmesinin yanı sıra ürün verimliliğinin de yükselmesine katkıda bulunmaktadır.

Yemleme yönetiminde dijital teknolojilerin bir diğer katkısı, sürdürülebilir üretim hedeflerine hizmet etmesidir. Daha verimli yem kullanımı, yalnızca ekonomik kazanç sağlamakla kalmamakta, aynı zamanda hayvancılığın çevresel ayak izini de azaltmaktadır. Daha az yem israfı ve daha dengeli besleme programları sayesinde sera gazı emisyonları düşmekte, bu da çevresel sürdürülebilirlik açısından önemli bir kazanım sunmaktadır (Halachmi vd., 2019).

Sonuç olarak, dijital yemleme ve besleme sistemleri hem maliyet avantajı sağlamakta hem de hayvanların performansını artırarak işletme kârlılığını güçlendirmektedir. Bu nedenle yemleme yönetiminde dijitalleşme, geleceğin hayvancılık işletmeleri için stratejik bir yatırım alanı olarak değerlendirilmektedir.

Süt Sağım Teknolojileri

Süt sığırcılığı işletmelerinde sağım, hem iş gücü maliyetlerinin yüksek olduğu hem de ürün kalitesi açısından kritik bir süreçtir. Geleneksel yöntemlerle yapılan sağım, zaman alıcı ve yoğun iş gücü gerektiren bir faaliyet olmasının yanı sıra, hijyen ve hayvan refahı açısından da bazı sınırlılıklar barındırmaktadır. Dijital tarım teknolojilerinin bir uzantısı olan robotik sağım sistemleri, bu süreçte önemli bir dönüşüm yaratmış ve işletmelere çok yönlü katkılar sunmaya başlamıştır.

Robotik sağım sistemleri (otomatik sağım makineleri), hayvanların bireysel olarak tanımlanmasını sağlayarak hem süt verimliliğini hem de süt kalitesini artırmaktadır. Bu sistemlerde entegre sensörler aracılığıyla süt miktarı, iletkenliği ve sıcaklığı gibi parametreler anlık olarak ölçülmekte, bu sayede meme sağlığı ve süt kalitesi hakkında üreticiye doğrudan geri bildirim verilmektedir. Ayrıca sağım işleminin hayvanların kendi tercihine göre gerçekleşmesi, stres seviyesini azaltmakta ve refah düzeyini yükseltmektedir (Jacobs ve Siegford, 2012).

Literatürde, robotik sağım teknolojilerinin ekonomik ve verimlilik etkilerine yönelik pek çok çalışma bulunmaktadır. Steeneveld vd. (2012), Hollanda'da yaptıkları araştırmada robotik sağım sistemlerinin süt üretiminde %5–7 arasında artış sağladığını ve iş gücü maliyetlerini kayda değer ölçüde azalttığını rapor etmiştir. Benzer şekilde, Hogeveen vd. (2010), robotik sağım sistemlerinin iş gücü bağımlılığını azaltarak özellikle büyük ölçekli işletmelerde önemli ekonomik avantajlar yarattığını, küçük ve orta ölçekli işletmelerde ise yüksek yatırım maliyetleri nedeniyle adaptasyonun daha sınırlı olduğunu vurgulamaktadır.

Süt sağım teknolojilerinin dijitalleşmesi yalnızca üretim süreçlerini optimize etmekle kalmamakta, aynı zamanda gıda güvenliği ve izlenebilirlik açısından da stratejik katkılar sunmaktadır. Sağım sırasında toplanan veriler, süt kalitesinin izlenmesine ve olası sağlık sorunlarının erken teşhis edilmesine imkân tanımaktadır. Bu durum, hem tüketici güvenini artırmakta hem de işletmelerin ürünlerini daha yüksek piyasa değerinden satabilmelerini mümkün kılmaktadır.

Sonuç olarak, dijital süt sağım teknolojileri hayvancılık işletmelerinde üretim süreçlerinin otomasyonunu sağlayarak verimlilik, kârlılık ve sürdürülebilirlik açısından kritik bir rol oynamaktadır. Önümüzdeki dönemde teknolojinin maliyetlerinin düşmesiyle birlikte, küçük ve orta ölçekli işletmelerde de yaygınlaşması beklenmektedir.

Sürü Yönetim Sistemleri

Sürü yönetimi, hayvancılık işletmelerinde verimlilik, üreme başarısı ve hastalıkların önlenmesi açısından kritik bir alanı oluşturmaktadır. Geleneksel sürü yönetimi yöntemleri, çoğunlukla üreticinin gözlemleri ve deneyimlerine dayalıdır; ancak bu yöntemler zaman alıcı, hataya açık ve büyük ölçekli işletmeler için yetersizdir. Dijital tarım uygulamaları ile geliştirilen akıllı sürü yönetim sistemleri, bu sınırlılıkları aşarak işletmelere entegre ve veriye dayalı bir yönetim imkânı sunmaktadır.

Bu sistemler, sensörlerden, IoT tabanlı cihazlardan ve yönetim yazılımlarından elde edilen verileri analiz ederek hayvanların sağlık durumu, üreme döngüsü, beslenme alışkanlıkları ve üretim performansı hakkında ayrıntılı bilgi sağlamaktadır. Örneğin, kızgınlık dönemindeki hareketlilik artışı pedometre veya GPS verileriyle tespit edilerek üreticiye bildirilmekte ve böylece döl tutma oranlarının artırılması mümkün olmaktadır (Friggens ve Chagunda, 2005). Aynı şekilde, doğum tahmini algoritmaları sayesinde doğum öncesi riskler önceden belirlenmekte, bu da hem hayvan refahı hem de buzağı kayıplarının azaltılması açısından önemli katkılar sunmaktadır.

Literatürde sürü yönetim sistemlerinin ekonomik faydalarını ortaya koyan pek çok çalışma bulunmaktadır. Moore ve Hasler (2017), ABD'de süt sığırcılığı işletmelerinde sürü yönetim yazılımlarının kullanımının, üreme başarısını artırarak sürüdeki gebelik oranlarını %10 oranında iyileştirdiğini rapor etmiştir. Ayrıca bu sistemlerin hastalıkların erken teşhisine olanak vermesi, tedavi maliyetlerini ve verim kayıplarını azaltarak işletme kârlılığını yükseltmektedir. Avrupa'da yapılan araştırmalar, sürü yönetim yazılımlarının kullanımının üreticiye yılda hayvan başına ortalama 100–150 € ekonomik katkı sağladığını göstermektedir (Calsamiglia vd., 2018).

Sürü yönetim sistemlerinin bir diğer avantajı ise iş gücü planlamasını kolaylaştırmasıdır. Dijital yazılımlar sayesinde sürüdeki hayvanların tüm verileri tek bir platformda toplanarak üreticiye günlük, haftalık ve aylık görev listeleri sunulmaktadır. Bu durum, özellikle büyük ölçekli işletmelerde iş yükünü azaltmakta ve yönetim süreçlerinde standardizasyon sağlamaktadır.

Sonuç olarak, dijital sürü yönetim sistemleri hayvancılıkta üretim etkinliğini artırmak, kayıpları azaltmak ve kârlılığı yükseltmek için stratejik bir araç olarak öne çıkmaktadır. Önümüzdeki dönemde yapay zekâ ve makine öğrenmesi entegrasyonu ile bu sistemlerin daha da akıllı hale gelmesi ve işletmelerin rekabet gücünü artırması beklenmektedir.

Çevresel Kontrol ve Enerji Yönetimi

Hayvancılık işletmelerinde üretim verimliliği ve hayvan refahı büyük ölçüde çevresel koşullara bağlıdır. Özellikle sıcaklık, nem, hava kalitesi ve aydınlatma koşulları hayvan sağlığı ve üretim performansını doğrudan etkilemektedir. Geleneksel yöntemlerde çevresel koşulların kontrolü çoğunlukla manuel yapılırken, dijital tarım uygulamaları sayesinde bu süreçler otomasyon sistemleri aracılığıyla sürekli ve hassas biçimde yönetilebilmektedir. IoT tabanlı sensörler, iklim kontrol yazılımları ve otomatik havalandırma sistemleriyle

donatılmış modern ahırlar, hayvanların optimum çevresel koşullarda yaşamasını sağlamaktadır (Brown-Brandl vd., 2005).
Çevresel kontrol sistemlerinin en önemli katkılarından biri, sıcaklık stresinin azaltılmasıdır. Özellikle süt sığırlarında sıcaklık stresi, süt veriminde düşüşe, döl tutma oranlarında azalmaya ve bağışıklık sisteminin zayıflamasına yol açmaktadır. Halachmi vd. (2019), otomatik iklim kontrol sistemlerinin kullanıldığı işletmelerde sıcaklık stresinin önemli ölçüde azaldığını ve bunun süt üretiminde %10'a varan artış sağladığını rapor etmiştir. Ayrıca nem ve hava kalitesini düzenleyen sensör tabanlı sistemler, solunum yolu hastalıklarının görülme sıklığını azaltarak hem veteriner maliyetlerini düşürmekte hem de sürü sağlığını iyileştirmektedir.
Enerji yönetimi de dijital tarımın önemli bileşenlerinden biridir. Akıllı enerji yönetim sistemleri sayesinde havalandırma, aydınlatma ve ısıtma-soğutma sistemleri gereksiz enerji tüketimini önleyecek şekilde optimize edilmektedir. ABD'de yapılan bir çalışmada, otomatik iklim ve enerji kontrol sistemlerinin kullanıldığı işletmelerde enerji tüketiminin %12 oranında azaldığı, bu sayede işletme maliyetlerinde kayda değer tasarruf sağlandığı ortaya konulmuştur (White, 2016). Bununla birlikte, yenilenebilir enerji kaynakları (güneş, biyogaz) ile entegre edilen dijital enerji yönetim sistemleri, çevresel sürdürülebilirliğe de katkıda bulunmaktadır.
Sonuç olarak, çevresel kontrol ve enerji yönetimine yönelik dijital uygulamalar, hem hayvan refahını artırmakta hem de işletmelerin ekonomik performansını güçlendirmektedir. Bu teknolojilerin yaygınlaştırılması, iklim değişikliğinin olumsuz etkilerinin azaltılmasına ve sürdürülebilir üretim hedeflerinin gerçekleştirilmesine yönelik stratejik bir adım olarak görülmektedir.

Ekonomik Katkılar

Dijital tarım teknolojilerinin hayvancılık sektöründe yaygınlaşmasının en önemli motivasyonlarından biri, sağladığı ekonomik kazanımlardır. Geleneksel üretim yöntemlerinde yüksek iş gücü bağımlılığı, yem ve enerji maliyetleri, hastalık kaynaklı kayıplar ve verimlilik düşüklüğü işletmelerin kârlılığını sınırlamaktadır. Dijitalleşme ile birlikte bu sorunların önemli ölçüde azaltıldığı, işletmelerin maliyet-etkinlik düzeylerinin yükseldiği görülmektedir.
İlk olarak, dijital teknolojiler iş gücü maliyetlerinde tasarruf sağlamaktadır. Robotik sağım sistemleri, otomatik yemleme makineleri ve gübre temizleme robotları gibi otomasyon çözümleri sayesinde iş gücü ihtiyacı azalmış, aynı zamanda üretim süreçleri standardize edilmiştir. Steeneveld vd. (2012), Hollanda'daki süt sığırcılığı işletmelerinde robotik sağım sistemlerinin iş gücü ihtiyacını %20'ye kadar düşürdüğünü, üreticiye yıllık ortalama 15.000 € tasarruf sağladığını rapor etmiştir.
İkinci olarak, dijital tarım uygulamaları verimlilik artışı ile ekonomik katkı sunmaktadır. Sensör tabanlı sağlık izleme sistemleri ve sürü yönetim yazılımları, hastalıkların erken teşhisine olanak vererek süt, et ve üreme performansındaki kayıpları azaltmaktadır. Rutten vd. (2013), sensör teknolojilerinin mastitis teşhisi için kullanılmasının tedavi maliyetlerini %20 azalttığını ve süt üretiminde %5'e varan artış sağladığını göstermiştir. Benzer şekilde, yapay zekâ tabanlı yemleme optimizasyonu, yemden yararlanma oranını artırarak yem maliyetlerinde düşüşe yol açmaktadır (García vd., 2020).
Üçüncü olarak, dijitalleşme ürün kalitesi ve piyasa değerini artırmaktadır. Sağım robotları ve izlenebilirlik sistemleri sayesinde süt kalitesinde süreklilik sağlanmakta, ürünler gıda güvenliği standartlarına uygun olarak pazara sunulmaktadır. Bu durum, özellikle tüketici güvenini yükseltmekte ve ürünlerin daha yüksek fiyatlarla satılmasına imkân tanımaktadır. Avrupa'da yapılan bir çalışmada, izlenebilirlik uygulamalarının süt ürünlerinin piyasa fiyatını %10–15 arasında artırdığı bildirilmiştir (Bertolini vd., 2006).
Son olarak, dijital tarım uygulamalarının kırsal kalkınma ve sürdürülebilirlik açısından da önemli ekonomik katkıları bulunmaktadır. Daha verimli kaynak kullanımı, hem çevresel maliyetlerin azaltılmasına hem de küçük ölçekli işletmelerin rekabet gücünün artmasına hizmet etmektedir. Özellikle IoT tabanlı enerji yönetim sistemleri, enerji tüketiminde %10–12 oranında tasarruf sağlayarak işletmelerin enerji maliyetlerini düşürmekte ve kâr marjlarını yükseltmektedir (White, 2016).
Genel olarak bakıldığında, dijital tarım teknolojileri hayvancılık sektöründe iş gücü tasarrufu, verimlilik artışı, maliyetlerin düşürülmesi, ürün kalitesinin iyileştirilmesi ve piyasa değerinin yükselmesi gibi çok boyutlu ekonomik faydalar sunmaktadır. Bu nedenle dijitalleşme, yalnızca bireysel işletmelerin kârlılığını artırmakla kalmamakta; aynı zamanda sektörün rekabetçiliğini ve kırsal kalkınma kapasitesini güçlendiren stratejik bir dönüşüm aracı olarak değerlendirilmektedir.

Sınırlılıklar ve Zorluklar

Her ne kadar dijital tarım teknolojileri hayvancılık sektörüne çok boyutlu katkılar sunsa da, uygulama aşamasında çeşitli sınırlılıklar ve zorluklarla karşılaşılmaktadır. Bu engellerin büyük kısmı, teknolojilerin maliyetinden, altyapı eksikliklerinden ve üreticilerin dijital okuryazarlık düzeylerinden kaynaklanmaktadır.
Yüksek yatırım maliyetleri, dijital tarım teknolojilerinin benimsenmesinde en büyük engel olarak öne çıkmaktadır. Robotik sağım sistemleri, otomatik yemleme robotları veya IoT tabanlı sensör ağları büyük ölçekli işletmeler için ulaşılabilirken, küçük ve orta ölçekli işletmeler için yüksek sermaye gerektirmesi nedeniyle erişim güçlüğü

yaratmaktadır. Steeneveld vd. (2012), özellikle küçük ölçekli süt sığırcılığı işletmelerinde robotik sağım sistemlerinin geri dönüş süresinin uzun olduğunu ve bu nedenle adaptasyonun sınırlı kaldığını belirtmektedir.

Dijital okuryazarlık ve eğitim eksiklikleri de bir diğer önemli sınırlılıktır. Yeni teknolojilerin etkin kullanımında üreticilerin teknik bilgi düzeyi kritik bir faktördür. Eastwood vd. (2019), üreticilerin dijital teknolojilere yönelik bilgi eksikliklerinin teknolojilerin tam kapasiteyle kullanılmasını engellediğini, bu nedenle yayım faaliyetlerinin önem taşıdığını vurgulamaktadır.

Altyapı sorunları, özellikle kırsal bölgelerde dijital tarımın yaygınlaşmasını sınırlayan bir diğer faktördür. İnternet erişimindeki yetersizlikler, elektrik kesintileri ve donanım eksiklikleri, IoT tabanlı sistemlerin sürekli çalışmasını engellemektedir. Bu durum, özellikle Türkiye gibi kırsal altyapının yeterince gelişmediği bölgelerde dijitalleşmenin hızını yavaşlatmaktadır.

Veri güvenliği ve mahremiyet endişeleri de dijitalleşmenin getirdiği yeni zorluklardan biridir. Sensörler, yazılımlar ve bulut tabanlı sistemler aracılığıyla toplanan büyük veri setlerinin güvenliğinin sağlanması, üreticilerin teknolojilere olan güvenini etkileyen kritik bir unsurdur. Ayrıca, farklı cihaz ve yazılımlar arasında standartlaşma eksikliği, verilerin entegrasyonunu zorlaştırmakta ve üreticiler açısından ek maliyet yaratmaktadır.

Son olarak, sosyo-ekonomik farklılıklar da dijitalleşme sürecinde önemli bir sınırlılık oluşturmaktadır. Büyük ölçekli işletmeler hızla dijitalleşirken küçük ölçekli aile işletmeleri bu dönüşümden geri kalmakta, bu da sektörde dijital uçurumun derinleşmesine yol açmaktadır. Bu durum, kırsal kalkınma hedefleri açısından uzun vadede eşitsizlik riskini beraberinde getirmektedir.

Tüm bu sınırlılıklar, dijital tarım teknolojilerinin yaygınlaştırılabilmesi için politika yapıcıların ve sektör paydaşlarının finansal destek, eğitim programları ve altyapı yatırımlarına öncelik vermesi gerektiğini göstermektedir.

Sonuç ve Öneriler

Dijital tarım teknolojileri, hayvancılık sektöründe üretim süreçlerinin modernleşmesine ve sürdürülebilirliğine önemli katkılar sunmaktadır. Sensörler, IoT tabanlı sistemler, yapay zekâ, robotik uygulamalar ve karar destek yazılımları sayesinde işletmeler; hayvan sağlığını ve refahını iyileştirmekte, verimliliği artırmakta ve maliyetlerini azaltmaktadır. Literatürdeki bulgular, dijitalleşmenin hastalıkların erken teşhisinden yemleme optimizasyonuna, süt sağımından çevresel kontrol sistemlerine kadar pek çok alanda hem teknik hem de ekonomik faydalar sağladığını göstermektedir.

Bununla birlikte, yüksek yatırım maliyetleri, dijital okuryazarlık eksiklikleri, altyapı sorunları ve veri güvenliği gibi sınırlılıklar, dijital tarımın yaygınlaşmasının önünde engel teşkil etmektedir. Özellikle küçük ve orta ölçekli işletmelerin bu teknolojilere erişimde zorlanması, sektörde dijitalleşme düzeyinde eşitsizliklere yol açmaktadır. Bu nedenle dijital tarımın sunduğu potansiyelin tam olarak hayata geçirilebilmesi için politika yapıcılar, araştırmacılar ve üreticilerin iş birliği içerisinde hareket etmesi gerekmektedir.

Çalışma neticesinde sektör paydaşları için aşağıdaki öneriler getirilmiştir;

İşletmeler için: Kademeli teknoloji adaptasyonu benimsenmeli, öncelikle en yüksek fayda sağlayacak sistemlerden başlanarak (ör. sağlık sensörleri, sürü yönetim yazılımları) dijitalleşme süreci planlanmalıdır.

Politika yapıcılar için: Küçük ve orta ölçekli işletmelerin dijitalleşmesini teşvik edecek hibe programları, düşük faizli krediler ve altyapı yatırımları hayata geçirilmelidir.

Eğitim ve yayım faaliyetleri: Üreticilerin dijital okuryazarlığını artırmaya yönelik eğitim programları yaygınlaştırılmalı, teknoloji firmaları ile üniversiteler arasında bilgi transferi mekanizmaları kurulmalıdır.

Araştırmacılar için: Dijital tarım teknolojilerinin ekonomik, sosyal ve çevresel etkilerini ölçen kapsamlı saha çalışmaları yapılmalı; yerel ihtiyaçlara uygun, maliyet-etkin çözümler geliştirilmelidir.

Sürdürülebilirlik için: IoT tabanlı enerji yönetimi, yenilenebilir enerji entegrasyonu ve çevresel izleme sistemleri öncelikli olarak desteklenmeli, böylece hayvancılığın çevresel ayak izi azaltılmalıdır.

Sonuç olarak, dijital tarım teknolojileri hayvancılık sektöründe verimlilik, kârlılık ve sürdürülebilirliği artıracak stratejik bir dönüşüm aracı olarak öne çıkmaktadır. Bu dönüşümün başarıya ulaşabilmesi için kamu desteği, üretici eğitimi, uygun finansman mekanizmaları ve araştırma-geliştirme faaliyetleri bir bütün olarak ele alınmalıdır. Böylece hem ulusal hem de küresel ölçekte hayvancılığın rekabet gücü artırılabilir ve gıda güvenliği hedeflerine katkı sağlanabilir.

Kaynaklar

García, R., Aguilar, J., Toro, M., Pinto, A., & Rodríguez, P. (2020). A systematic literature review on the use of machine learning in precision livestock farming. *Computers and Electronics in Agriculture*, *179*, 105826.

Bertolini, M., Bevilacqua, M., & Massini, R. (2006). FMECA approach to product traceability in the food industry. *Food Control, 17*(2), 137–145. https://doi.org/10.1016/j.foodcont.2004.09.013

Moore, S. G., & Hasler, J. F. (2017). A 100-Year Review: Reproductive technologies in dairy science. *Journal of dairy science*, *100*(12), 10314-10331.

Borchers, M. R., & Bewley, J. M. (2015). An assessment of producer precision dairy farming technology use, preparedness, and perceptions. *Journal of Dairy Science, 98*(9), 6229–6246. https://doi.org/10.3168/jds.2015-9316

Caja, G., Castro-Costa, A., & Knight, C. H. (2016). Engineering to support wellbeing of dairy animals. *Journal of Dairy Research, 83*(2), 136–147. https://doi.org/10.1017/S0022029916000261

Bhuiyan, M. R., & Wree, P. (2023). Animal behavior for chicken identification and monitoring the health condition using computer vision: A systematic review. *IEEE access*, *11*, 126601-126610.

Eastwood, C., Klerkx, L., Ayre, M., & Dela Rue, B. (2019). Managing socio-ethical challenges in the development of smart farming: From a fragmented to a comprehensive approach for responsible research and innovation. *Journal of Agricultural and Environmental Ethics, 32*(5-6), 741–768. https://doi.org/10.1007/s10806-019-09816-0

Food and Agriculture Organization of the United Nations (FAO). (2020). *The State of Food and Agriculture 2020: Overcoming water challenges in agriculture*. FAO. https://doi.org/10.4060/cb1447en

Friggens, N. C., & Chagunda, M. G. G. (2005). Prediction of the reproductive status of cattle on the basis of milk progesterone measures: Model description. *Theriogenology, 64*(1), 155–190. https://doi.org/10.1016/j.theriogenology.2004.11.014

Brown-Brandl, T. M., Jones, D. D., & Woldt, W. E. (2005). Evaluating modelling techniques for cattle heat stress prediction. *Biosystems Engineering*, *91*(4), 513-524.

Halachmi, I., Guarino, M., Bewley, J., & Pastell, M. (2019). Smart animal agriculture: Application of real-time sensors to improve animal well-being and production. *Annual Review of Animal Biosciences, 7*, 403–425. https://doi.org/10.1146/annurev-animal-020518-114851

Hogeveen, H., Kamphuis, C., Steeneveld, W., & Mollenhorst, H. (2010). Sensors and clinical mastitis—The quest for the perfect alert. *Sensors, 10*(9), 7993. https://doi.org/10.3390/s100907991

Jacobs, J. A., & Siegford, J. M. (2012). Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. *Journal of Dairy Science, 95*(5), 2227–2247. https://doi.org/10.3168/jds.2011-4943

Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2017). A review on the practice of big data analysis in agriculture. *Computers and Electronics in Agriculture, 143*, 23–37. https://doi.org/10.1016/j.compag.2017.09.037

Liakos, K. G., Busato, P., Moshou, D., Pearson, S., & Bochtis, D. (2018). Machine learning in agriculture: A review. *Sensors, 18*(8), 2674. https://doi.org/10.3390/s18082674

White, R. R. (2016). Increasing energy and protein use efficiency improves opportunities to decrease land use, water use, and greenhouse gas emissions from dairy production. *Agricultural Systems*, *146*, 20-29.

Rutten, C. J., Velthuis, A. G. J., Steeneveld, W., & Hogeveen, H. (2013). Invited review: Sensors to support health management on dairy farms. *Journal of Dairy Science, 96*(4), 1928–1952. https://doi.org/10.3168/jds.2012-6107

Steeneveld, W., Tauer, L. W., Hogeveen, H., & Oude Lansink, A. G. J. M. (2012). Comparing technical efficiency of farms with an automatic milking system and a conventional milking system. *Journal of Dairy Science, 95*(12), 7391–7398. https://doi.org/10.3168/jds.2012-5737

Calsamiglia, S., Astiz, S., Baucells, J., & Castillejos, L. (2018). A stochastic dynamic model of a dairy farm to evaluate the technical and economic performance under different scenarios. *Journal of dairy science*, *101*(8), 7517-7530.

Alawneh, J. I., Henning, J., & Olchowy, T. W. (2018). Functionality and interfaces of a herd health decision support system for practising dairy cattle veterinarians in New Zealand. *Frontiers in Veterinary Science*, *5*, 21.

Tzounis, A., Katsoulas, N., Bartzanas, T., & Kittas, C. (2017). Internet of Things in agriculture, recent advances and future challenges. *Biosystems Engineering, 164*, 31–48. https://doi.org/10.1016/j.biosystemseng.2017.09.007

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big Data in Smart Farming – A review. *Agricultural Systems, 153*, 69–80. https://doi.org/10.1016/j.agsy.2017.01.023

The Rise of Digital Agriculture and Sustainable Production with Smart Technologies

Zeynep Ünal[1]

[1] Biosystems Engineering, Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University, Turkey

Abstract

The agricultural sector has reached a critical juncture in its historical development through the process of digitalization. Moving beyond traditional methods, digital agricultural practices are rapidly expanding with the integration of advanced technologies such as sensors, the Internet of Things, artificial intelligence, big data analytics, unmanned aerial vehicles, and autonomous land systems into production processes. These innovations facilitate real-time data collection, enable precise monitoring of environmental conditions, and support production decisions grounded in scientific analysis. Therefore, digitalization not only increases production efficiency and quality but also contributes to the sustainable use of natural resources. One of the most striking aspects of this transformation is the capacity to develop solutions for anticipated future food security challenges. Under the pressure of increasing populations and climate change, ensuring a predictable, traceable, and resilient agricultural structure has become a global strategic imperative. Digital agriculture enables both economic and environmental sustainability in production through precision farming practices and intelligent decision support systems. This study comprehensively examines the rise of digital agriculture and, in particular, discusses the impact of smart technologies on sustainable production. The findings show that digitalization in agricultural production will play a critical role not only in today's but also in future agricultural policies and strategies.

Key Words: *Agricultural Technologies, Digital Agriculture, Smart Agriculture, Precision Agriculture, Artificial intelligence*

Tarım Dijital Tarımın Yükselişi ve Akıllı Teknolojilerle Sürdürülebilir Üretim

Özet

Tarım sektörü, dijitalleşme süreciyle birlikte tarihsel gelişiminde önemli bir kırılma noktasına ulaşmıştır. Geleneksel yöntemlerin ötesine geçen dijital tarım uygulamaları, sensörler, nesnelerin interneti, yapay zekâ, büyük veri analitiği, insansız hava araçları ve otonom kara sistemleri gibi ileri teknolojilerin üretim süreçlerine entegrasyonu ile giderek daha yaygın bir hale gelmektedir. Bu teknolojilerin sektöre sunduğu imkanlar sayesinde uygulama alanlarda anlık veri toplanabilmek çok daha kolay hale gelmiştir. Artık çevresel faktörler bu sayede daha hassas biçimde izlenebilmekte ve üretim kararları buradan çıkan sonuçlara dayalı daha bilimsel olarak alınabilmektedir. Dolayısıyla dijitalleşme, yalnızca üretim verimliliğini ve kaliteyi artırmakla kalmamakta, aynı zamanda kolay kullanıma da katkı sağlamaktadır. Ayrıca gelecekte beklenen gıda krizine yönelik çözüm geliştirme kapasitesi de oldukça önemlidir. Artan nüfus ve iklim değişikliği baskısı altında, tarımın izlenebilir ve esnek bir yapıya kavuşması ve daha önemlisi öngörülebilir olması artık bir zorunluluk haline gelmiştir. Bu çalışma, dijital tarımı kavramını kapsamlı biçimde ele almakta ve özellikle akıllı teknolojilerin kullanım allananlarını ve üretim üzerindeki etkilerini tartışmaktadır. Elde edilen bulgular, tarımsal üretimde dijitalleşmenin yalnızca günümüzün değil, aynı zamanda geleceğin tarımsal politikaları ve stratejileri açısından da kritik bir rol oynayacağını göstermektedir.

Anahtar Kelimeler: *Tarım Teknolojileri, Dijital Tarım, Hassas Tarım, Akıllı Tarım, Yapay Zeka*

Giriş

Tarım, insanlık tarihi boyunca temel ihtiyaçların karşılanmasında kritik bir öneme sahip olarak ekonomik ve sosyal kalkınmanın vazgeçilmez bir unsuru olmuştur. Türkiye'de ise tarım sektörünün stratejik önemi, tarihsel olarak güçlü bir üretim kültürüne dayanmasından kaynaklanmaktadır (Büyükokutan & Söğüt, 2022). Tarımsal üretim, bir çok disiplinin içerisinde barındırdığı ve karmaşık süreçlerin bütünleştiği çok boyutlu bir sisteme sahiptir (Swanson, 1979). İklim, toprak yapısı, hastalıklar ve çevresel faktörler bu sistemi doğrudan etkilediğinden yalnızca teorik bilgi değil, çevresel koşulların yönetimi de başarı için belirleyici olmaktadır (Özgüven, 2023).

Son yıllarda yaşanan nüfus artışı, iklim değişikliği ve iş gücü maliyetlerindeki artış, tarımda dijitalleşme ve otomasyonu kaçınılmaz hâle getirmiştir (İnan & Karcı, 2021). Tarımsal üretim tarihsel olarak dört evrede özetlenebilir. Bu evreler sırayla, Tarım 1.0 insan gücü, Tarım 2.0 mekanizasyon, Tarım 3.0 hassas tarım ve son olarak tarım 4.0 dijitalleşme sürecidir (Şahin, 2022). Bu son evre, aynı zamanda Dijital Tarım olarak adlandırılmakta ve sensörler, yapay zekâ, büyük veri ve otonom sistemlerinin entegrasyonunu içermektedir (Aydın, 2022). Bu teknolojiler sayesinde çiftçiler, toprak, ürün ve iklim gibi erişimi zor verilere anlık olarak ulaşarak daha doğru kararlar alabilmekte, böylece üretimde sürdürülebilirlik ve verimlilik sağlanmaktadır (Sevli, 2023).

Bu çalışmanın temel amacı, literatürde sıklıkla birbirinin yerine kullanılan "hassas tarım", "akıllı tarım" ve "dijital tarım" gibi kavramları tanımsal çerçeveleriyle birlikte açık bir şekilde ortaya koymaktır. Böylece, tarım teknolojileri alanında karşılaşılan kavramsal belirsizliklerin giderilmesi, terminolojik tutarlılığın sağlanması ve gelecekte bu konularda yapılacak akademik ve uygulamalı çalışmalara kuramsal bir temel sunulması hedeflenmektedir.

Dijital Tarım Kavramı

Hassas tarım, akıllı tarım ve dijital tarım kavramları, tarımsal üretimde teknolojinin giderek artan rolü ile birlikte ortaya çıkan ve tarım teknolojilerinin evrimsel sürecini yansıtan, birbirinden farklı ancak ilişkili yaklaşımlardır (Alakuş & Türkoğlu, 2024). Her üç kavram da, üretim süreçlerinde verimliliği artırmak, kaynak kullanımını optimize etmek ve çevresel sürdürülebilirliği sağlamak amacıyla süreci kolaylaştıracak araçların entegrasyonunu hedeflemektedir (Beluhova-Uzunova & Dunchev, 2022). Bununla birlikte, bu kavramlar sıklıkla birbirinin yerine kullanılsa da, içerik ve uygulama bağlamında belirgin farklılıklar içermektedir (Ünal & Kızıldeniz, 2023). Tarımda dijitalleşmenin hız kazanmasıyla birlikte, söz konusu kavramlar literatürde zaman zaman eş anlamlı olarak değerlendirilmiş ve bu durum kavram kargaşasına yol açmıştır (Beluhova-Uzunova & Dunchev, 2022). Ancak, bu kavramsal belirsizliğin giderilmesi amacıyla, 2018 yılında Alman Tarım Topluluğu tarafından düzenlenen bir çalıştayda, hassas tarım, akıllı tarım ve dijital tarım terimlerinin kapsamları netleştirilmiş ve her birinin özgün nitelikleri açık bir şekilde tanımlanmıştır (DLG, 2025). Bu bağlamda, bu kavramlar arasındaki farklılıkların doğru bir şekilde anlaşılıyor olması, tarım teknolojilerinin sunduğu yeniliklerin etkin bir biçimde yorumlanması ve uygulanması açısından büyük bir öneme sahiptir.

Hassas Tarım

Hassas Tarım, tarımsal üretim süreçlerinin etkinliğini artırmak ve çevresel etkileri en aza indirmek amacıyla teknoloji ve veri temelli uygulamaların entegrasyonunu esas alan modern bir yönetimsel tarım yaklaşımıdır (Mandal & Ghosh, 2000). Bu yöntem, toprak özellikleri, sulama gereksinimleri, pH düzeyleri ve diğer çevresel parametrelerin detaylı analizine dayanarak her tarım parseline özgü uygulamaların geliştirilmesini sağlamaktadır. İlk olarak 1980'lerde, hassas tarımın babası olarak bilinen Dr. Pierre Robert tarafından ortaya atılan bu fikir, zamanla tarımın can damarı haline gelerek kapsamlı bir araştırma alanına dönüşmüştür (Rust & Robert , 1980). Gelişmiş teknolojilerin kullanımı yaygın olmayan o yıllarda basit el tipi cihazlarla ölçümlerin yapılmasıyla uygulanan Hassas Tarım, üretim maliyetlerini düşürmek ve kaynak kullanımını optimize etmek üzere geliştirilmiştir (Quebrajo, Pérez-Ruiz, Rodriguez-Lizana, & Agüera, 2015). Ayrıca mikro-değişkenliklerin dikkate alınması durumunda sensörler ve haritalama sistemlerini kullanarak ihtiyaca yönelik uygulamaların yapılması ile minimum kaynak kullanımı ile maksimum verim sağlanmaktadır (Bozdağ, ve diğerleri, 2025). Uygulamalarda girdi optimizasyonu ve maliyetin düşürülmesi ön planda tutulmakta ve karar alma süreci otomatik çalışan sistemlere dayalı olmadan genellikle çiftçinin desteğiyle sağlanmaktadır. Bu nedenle ürün yetiştirilen alanın tamamına yönelik homojen uygulamalar yerine, arazi içerisindeki değişkenlikleri dikkate alan farklılaştırılmış müdahaleler yapılmaktadır (Colaço & Molin, 2017). Böylece örneğin, gübre uygulaması ihtiyaç temelli gerçekleştirildiği için hem ekonomik hem de ekolojik fayda sağlamaktadır. Özetle Hassas Tarım, gözlem ve ölçüme dayalı yönetim yaklaşımlarıyla doğru zamanda, doğru yerde ve doğru müdahaleyi gerçekleştirmeyi amaçlayan bir sistemdir (Keskin, Şekerli, Say, & Arslan, 2018).

Akıllı Tarım

Akıllı tarım, bilişim teknolojilerin tarımsal üretime entegre edilmesiyle süreçleri daha verimli, otomatik ve veriye dayalı hale getiren bir yaklaşımdır (Tantalaki, Souravlas, & Roumeliotis, 2019). Bu yaklaşımda cihazlar yalnızca veri toplamakla kalmaz, aynı zamanda bu verileri işleyerek karar almada kullanılabilecek bir bilgi tabanı oluşturmaktadır (Velamuri, 2023). Akıllı tarım, hassas tarımın daha gelişmiş bir formu olup, çiftçilere iklim, toprak ve bitki verilerine gerçek zamanlı erişim sunarak bilinçli karar alma olanağı sağlamaktadır. Böylece daha az insan gücüyle daha yüksek miktar ve kalitede ürün elde edilmesi mümkün olmaktadır (Walter, Finger, Huber, & Buchmann, 2017). Akıllı tarım, bitkilerin ihtiyaç duyduğu su, besin ve bakım gibi girdileri doğru zamanda ve miktarda sağlayarak birim alandan en yüksek verim elde etmenin yanında karar destek mekanizmaları ile uygulama kaynaklı hataların önüne geçme amacı taşımaktadır. Otomasyon ve IoT ile gerçek zamanlı uzaktan kontrol sağlayarak sulama ve gübreleme gibi işlemleri otomatik gerçekleştirilmesini mümkün kılmaktadır (Li & Niu, 2020). Ayrıca ürün izlenebilirliği, üretim planlaması ve rekolte tahmini gibi konularda da önemli katkılar sunmaktadır (Ağızan, Bayramoğlu, & Ağızan, 2022).

Dijital Tarım

Dijital tarım, bilişim sistemlerinin ve yüksek teknoloji aygıtlarının bir araya gelerek oluşturduğu modern bir tarım yaklaşımını ifade etmektedir. Literatürde 2016 yılından sonra yer almaya başlayan Dijital tarım kavramının bir çok çalışmada eş anlamlı olarak kullanıldığı görülmüştür (Keogh & Henry, 2016). 2018 yılında Alman Tarım Topluluğu tarafından düzenlenen bir çalıştayda dijital tarım terimi açık bir şekilde tanımlanmıştır (DLG, 2025). Dijital tarım, tarımsal üretim süreçlerinin dijital teknolojiler aracılığıyla bütüncül biçimde yönetilmesini amaçlayan bir yaklaşımdır. Sensör teknolojileri, büyük veri analitiği, bulut bilişim, yapay zeka, nesnelerin interneti (IoT), coğrafi bilgi sistemleri (CBS), insansız araçlar ve web tabanlı veri platformları gibi çeşitli dijital araç ve sistemler entegre bir şekilde kullanılarak, tarımsal faaliyetlerde veri odaklı ve bilinçli karar alma süreçleri desteklenmektedir (Paraforos & Griepentrog, 2021). Dijital tarım, çoğunlukla üretim verimliliğini artırma ve iklim değişikliğine adaptasyonu sağlama gibi hedeflerle uygulanırken, yalnızca üretim süreçleriyle sınırlı kalmayıp tedarik zinciri yönetimi, pazarlama, girdi temini ve çiftlikler arası iş birlikleri gibi alanları da kapsamaktadır (Zakota, 2024). Bu yönüyle dijital tarım, hassas tarım ve akıllı tarım yaklaşımlarını da içinde barındırırken onlardan daha geniş bir dijital dönüşüm çerçevesi sunmaktadır (Dayıoğlu & Türker, 2021). Dijital tarım, hassas tarım ve akıllı tarım yaklaşımlarının ötesine geçerek iç ve dış tüm tarımsal süreçlerin dijital ekosistem içinde bütünsel biçimde yönetilmesini hedeflemektedir (Göl & Tarhan, 2024).

Dijital Tarım Teknolojileri

Dijital tarımda, üretim süreçlerinin optimize edilmesi ile veri toplama, analiz ve değerlendirme aşamalarında çeşitli ileri teknolojiler başarıyla kullanılmaktadır. Bu teknolojiler arasında Uzaktan Algılama, İnsansız Hava Araçları, Sensörler, İnsansız Kara Araçları, Makine Öğrenmesi, Bulanık Mantık, Nesnelerin İnterneti yer almaktadır. Tüm bu teknolojiler, Karar Destek Sistemleri içerisinde entegre bir şekilde kullanılarak çiftçilere bütüncül ve veriye dayalı çözümler sunmaktadır (Çakmakçı & Çakmakçı, 2023). Bu teknolojilerin uygun kombinasyonları, akıllı tarım uygulamaları kapsamında üretkenliği artırmakta ve çiftçilerin karar verme süreçlerini desteklemektedir (Dayıoğlu & Türker, 2021).

Karar Destek Sistemleri (KDS)

Karar destek sistemi, iş veya organizasyonel karar alma faaliyetlerini destekleyen bir bilgi sistemidir. Bir organizasyonun yönetim, operasyon ve planlama düzeylerine hizmet eden bu sistemler, insanların önceden kolayca belirlenemeyen sorunlar hakkında hızlı karar almalarına yardımcı olmaktadır. 1970'li yıllarda ortaya atılan bu yaklaşım bilgi teknolojileri gelişmesi ile beraber bir çok iş dalında kullanılmaya başlanmıştır (Power, 2008). Karar destek sistemleri, tarımda da yaygın olarak kullanılmakta olup verilerin analiz edilmesi, çıkarımlar yapılması ve bilgi kaynağı oluşturulmasını sağlamaktadır. Tarımda karar destek sistemlerinin kullanımı özellikle, sulama kaynaklarının yönetiminde, görev planlamasında, iklim değişikliğine uyum sağlanmasında, israfın önlenmesi ve atık yönetiminde, tarımsal tedarik zincirlerinde ve sürdürülebilirlik konularında öne çıkmaktadır (Zhai, Martínez, Beltran, & Martínez, 2020). Bir karar destek sistemi, bir bilgi tabanı, yazılım ve bir kullanıcı arayüzünden oluşmaktadır. Bilgi tabanı, sistemin muhakeme motoru tarafından kullanılan dahili ve harici kaynaklardan gelen bilgileri depolamaktadır (Wang, 1997). Yazılım sistemi, gerçek dünya sistemlerini simüle ederek çalışma biçimlerini anlayan ve iyileştiren model yönetim sistemlerinden oluşmaktadır (Shim, ve diğerleri, 2002). Modeller, karmaşık, pahalı veya tehlikeli sistemler için ve bir sistemdeki değişikliklerin sonuçlarını tahmin etmek için kullanılmaktadır. Kullanıcı arayüzü, kolay gezinme ve veri manipülasyonu sağlamaktadır. Yapay zeka teknolojilerine dayalı akıllı karar destek sistemleri bilişsel karar alma işlevlerini de gerçekleştirmektedir.

Nesnelerin İnterneti (IOT) ve Sensörler

Nesnelerin İnterneti, kablosuz iletişim teknolojilerindeki gelişmelerle birlikte giderek önem kazanan bir kavramdır. IoT, fiziksel nesnelerin standart iletişim protokolleri aracılığıyla internete bağlanarak birbirleriyle veri alışverişi yapmasını sağlamaktadır. Bu sayede insan müdahalesi olmaksızın cihazlar arasında senkronize bilgi iletimi, veri toplama ve karar alma süreçleri mümkün hale gelmektedir (Gündüz & Daş, 2018).

Sensörler aracılığıyla fiziksel çevreden veri toplayarak dijital ortama aktaran bu aygıtlar, toprağın pH değeri, nem, sıcaklık ve yağış gibi verileri gerçek zamanlı olarak ölçülmesini mümkün kılmaktadır. Ancak farklı sensör üreticilerinin veri toplama yöntemleri arasında farklılıklar bulunması, tutarsızlıklara ve dolayısıyla hatalı kararlara yol açabileceğinin bilinmesi oldukça önemlidir (Aydın, 2022). Tarım alanında çevresel ve biyolojik parametrelerin izlenmesine yönelik olarak çeşitli işlevlere sahip sensör teknolojilerinin bulunması, bu aygıtların yönetimini uzmanlık gerektiren bir konu haline getirmiştir. Yaygın alarak kullanılan sensörler arasında olan optik sensörler, hayvan, biyoçeşitlilik, zararlı organizmalar, bitki sağlığı, stres düzeyi ve gelişim durumu gibi unsurları değerlendirmeye yönelik görüntü verileri toplamaktadır (Özgüven, 2023). Ayrıca bitkinin gelişimini etkileyen toprak besin içeriğine ilişkin veriler elektrokimyasal sensörler ile toplanmaktadır. Bunların dışında da kullanım alanı bulan konum sensörleri, küresel konumlama sistemleri aracılığıyla mekânsal veri sağlayarak dijital tarım uygulamalarına katkı sunmaktadır. Son olarak bir çok sensörü içerisinde barındıran meteoroloji istasyonları, uygulama alanlarının farklı noktalarına yerleştirilerek hava akışı, güneş radyasyonu, yaprak nemi, mevsimsel yağış, nem oranı, rüzgâr hızı ve yönü ile atmosfer basıncı gibi meteorolojik değişkenleri izlemeye imkân vermektedir (Çakmakçı & Çakmakçı, 2023).

İnsansız Kara Araçlar (İKA) ve İnsansız Hava Araçları (İHA)

Yapay zekâ ve uzaktan algılama teknolojilerinin tarıma entegrasyonu ile birlikte, insansız robot sistemlerinden elde edilen faydalar da artmıştır. Bu robotlar, veri toplama sürecini hızlandırmakta, veri standardizasyonunu kolaylaştırmakta ve öznel hataları azaltarak daha güvenilir veri setleri oluşturmaktadır. Tarımsal uygulamalarda kullanılan İnsansız Kara Araçları (İKA), çoklu sensörlerle donatılarak yere temas halinde uzaktan kumanda ile veya otonom şekilde hareket ederek veri toplamak veya verilen görevi gerçekleştirmek için kullanılmaktadır (Zhao, Li, Li, Zhang, & Guo, 2013). İnsan müdahalesi olmadan otonom bir şekilde şarj istasyonlarına gelerek şarjını tamamlayarak görevine devam edebilen bu araçların insan sağlığını tehlikeye atacak görevler için kullanımı bu araçları avantajlı hale getirmektedir. Ancak bu araçların meyve bahçelerinde sıra aralıklarına uygun palet genişliği, tarlada yetişen bitkinin boyuna göre yeterli uygulama yüksekliği ve engebeli arazilerde denge için süspansiyon sistemlerinin varlığını gibi belirli yapısal özelliklerinin bulunması gerekmektedir. (Kırçıl & Tepe, 2024). İnsansız Hava Araçları (İHA) ise, uluslararası tanımlamalara göre insan taşımayan, manuel ya da otomatik olarak kontrol edilebilen sistemlerdir (Kahveci & Can, 2017). Temel olarak faydalı yük, yer kontrol istasyonu ve aviyonik sistemden oluşan bu araçlar, tarımsal görüntüleme, ilaçlama veya veri iletiminde kullanılmaktadır. Üzerinde bulunan küresel konumlandırma sistemi ve sensör sistemleri sayesinde uçuş rotası ve manevraları otomatik olarak koordine edebilmektedir (Kırçıl & Tepe, 2024). Tüm operasyonları havadan gerçekleştiren bu araçlar, engebeli ve dik eğimi olan araziler için vazgeçilmez hale gelmiştir, ancak bataryanın kapasitesi aracın havada kalma süresini kısıtladığından ve yük kaldırma kapasitesinin sınırlı olmasından dolayı bu araçların tarımsal faaliyetlerde uzun süreli kullanım durumu azalmakta veya geniş alanlı uygulamalarda verimliliği düşebilmektedir (Mohsan, Khan, Noor, Ullah, & Alsharif, 2022). Bu nedenle, batarya teknolojilerinin geliştirilmesi ve görev optimizasyonuna yönelik stratejiler, bu sistemlerin daha etkin kullanılabilirliği açısından kritik bir önem taşımaktadır. Son olarak zirai mücadele amacıyla kullanılan insansız hava araçlarının uygun olmayan irtifalarda operasyonun gerçekleştirmesi pestisit veya sıvı uygulamalarında sürüklenme (drift) olgusunu artırmaktadır. Bu durum hedef dışı alanlara kimyasal taşınımına yol açarak uygulama alanı dışındaki bitkisel üretimlere zarar verme riskini beraberinde getirmektedir. Özellikle rüzgar, nem ve sıcaklık gibi faktörlerin etkisiyle bu etki daha da şiddetlenebilmektedir. Bu nedenle, uçuş yüksekliği, hava koşulları ve uygulama tekniklerinin dikkatle seçilmesi bu tür istenmeyen etkileri azaltacaktır.

Küresel Konumlandırma Sistemi (GPS) ve Coğrafi Bilgi Sistemi (CBS)

Küresel Konumlandırma Sistemi (GPS), Dünya yörüngesindeki uydular aracılığıyla yeryüzündeki alıcılara konum bilgisi sağlayan bir navigasyon sistemidir. GPS nesne ya da bireylerin yersel koordinatlarının belirlenmesinde, uydular aracılığıyla gönderilen elektromanyetik sinyallerin alıcı cihazlar tarafından analiz edilmesi yoluyla konumsal veri sağlamaktadır. Bu teknoloji, hassas konum belirleme gerektiren tarım, ulaşım, afet yönetimi ve otonom sistemler gibi çeşitli alanlarda temel bir bileşen olarak kullanılmaktadır. Bununla birlikte, sinyalin atmosferik bozunmalar, fiziksel engeller veya çok yollu yayılma gibi çevresel faktörlerden etkilenmesi, sistemin konumsal doğruluğunu ve güvenilirliğini sınırlayabilmektedir. Tarımda GPS, çiftçilerin toprak örnekleri toplamak veya ürün durumu izlemek için her yıl aynı noktaya hassas şekilde ulaşmalarını sağlamaktadır. Ayrıca tarla sınırları, yollar, sulama sistemleri ve sorunlu alanların haritalanmasında yaygın olarak kullanılmaktadır.

Coğrafi Bilgi Sistemi (CBS) ise coğrafi verileri toplamak, depolamak, analiz etmek ve görselleştirmek için kullanılan bilgisayar tabanlı bir sistemdir. GPS, nesnelerin veya bireylerin konumunu belirlerken, bu veriler CBS yazılımlarıyla analiz edilerek harita ve karar destek verisine dönüştürmektedir. Uygulamalarda GPS'ten elde edilen veriler, CBS ortamına aktarılmakta ve burada analiz edilerek dijital tarım uygulamalarına katkı sunmaktadır (Görmez & Ertaş, 2019). Bu entegrasyon sayesinde, tarımsal faaliyetlerin mekânsal olarak izlenmesi, arazi kullanım planlaması, hassas ilaçlama ve gübreleme gibi uygulamaların etkinliğinin artırılması yönünde stratejiler üretilebilmektedir. Dolayısıyla, GPS ve CBS teknolojilerinin birlikte kullanımı, veri odaklı karar alma süreçlerini destekleyerek dijital tarım açısından önemli bir araç konumundadır.

Yapay Zeka

Yapay zekâ, doğal sistemlerin gerçekleştirebildiği bilişsel faaliyetlerin, yapay sistemler tarafından daha yüksek performans düzeylerinde yerine getirilmesini inceleyen bir bilim dalıdır (Dobrev, 2005). Yapay zekanın alt dalı olan makine öğrenmesi ise son yıllarda tarımda geniş kullanım alanı bulmuştur. Makine öğrenmesi insanın düşünme mekanizması temel alınarak geliştirilen bir yaklaşımdır (Lake, Ullman, Tenenbaum, & Gershman, 2017). İnsanın bilgiyi işleme yeteneği daha önce edinilmiş tecrübeye diğer bir ifade ile öğrenmesine bağlı olup, öğrenme ise bilgiye bağlıdır. İnsanın bilişsel faaliyetleri veya bilgiyi işleme kapasitesi, öğrenme süreçleriyle kazanılmış bilişsel birikime dayanmaktadır. Öğrenme ise temelde bilgi edinimiyle doğrudan ilişkili olup, bireyin çevresel uyarıcılardan elde ettiği verileri anlamlandırma ve yapılandırma süreci olarak tanımlanabilir (Morik, 1991). İnsanın öğrenme süreçlerinde bilginin işlenip anlamlandırılması nasıl temel bir rol oynuyorsa, makine öğrenmesi algoritmalarında da benzer biçimde, büyük veri kümeleri üzerinden desenlerin ve ilişkilerin çıkarılması yoluyla öğrenme gerçekleştirilir. Bu bağlamda, makine öğrenmesi, istatistiksel modeller ve algoritmalar aracılığıyla veriden anlamlı sonuçlar üretmeyi amaçlayan, veri odaklı bir öğrenme yaklaşımıdır.

Tarımda yapay zekâ uygulamaları ile tahmine dayalı analitik yöntemlerin entegrasyonu, üretim süreçlerinin daha öngörülebilir ve optimize edilebilir hale gelmesini sağlamaktadır (Javaid, Haleem, Khan, & Suman, 2023). Bu teknolojilerle bağlantılı olarak kullanılan sensör sistemleri ise, bitki verimliliğinin artırılmasının yanı sıra, su, besin elementleri ve diğer tarımsal girdilerin kullanımında kaynak verimliliğini yükseltme potansiyeline sahiptir. Uzaktan algılama teknolojileri ile birlikte veri toplama, analiz, depolama, yönetim, aktarım, paylaşım, iletişim ve işleme alanlarında yaşanan teknolojik gelişmeler, büyük veri transferini ve analitik süreçlerin otomasyonunu mümkün kılmıştır (Martos, Ahmad, Cartujo, & Ordoñez, 2021).

Yapay zeka teknolojileri, tarımda zorluklarla başa çıkmak için çeşitli yöntemler sunmaktadır. Yapay Zeka, makine öğrenimi, derin öğrenme, görüntü işleme gibi tekniklerle bir çok karmaşık görevi hızlı ve tutarlı şekilde yerine getirmektedir. Mahsul izleme, hastalık tespiti, zararlıları tespiti, yabancı ot tespiti, bitki sınıflandırması (fenotipleme), arazi örtüsü tanımlanması, toprak hatalarının teşhisi, hassas hayvancılık, nesne tanıma, akıllı sulama ev hava durumu tahminleri gibi uygulamalar yapay zekanın tarımda kullanıldığı başlıca alanlardandır. Ayrıca, bu teknolojiler, çiftçilerin uygun ürün seçiminden fiyat tahminlerine kadar birçok alanda kararlarını iyileştirmelerini sağlamakta ve dijital çiftçilik uygulamalarıyla kayıpların azaltmasına imkan vermektedir (Öztürk, Eminoğlu, & Küçükyıldırım, 2025).

Sonuç

Küresel düzeyde yaşanan iklim değişikliği, su kaynaklarının azalması ve nüfus artışı gibi dinamikler, tarımsal üretimde verimlilik ve sürdürülebilirlik gereksinimini daha da ön plana çıkarmaktadır. Bu bağlamda, dijitalleşme süreci tarım sektörü için kaçınılmaz bir dönüşüm alanı haline gelmiştir. Bu çalışmada ele alınan dijital tarım kavramı, geleneksel üretim yapılarından farklı olarak, yüksek teknoloji entegrasyonuna dayalı bir üretim modeli sunmaktadır. Sensör sistemleri, otomasyon teknolojileri, robotik uygulamalar ve yapay zekâ tabanlı karar destek mekanizmaları ile tarımsal üretim süreçleri daha hassas, izlenebilir ve sürdürülebilir bir yapıya kavuşmaktadır.

Veri toplama teknikleri ve bu verilerin işlenmesi dijital tarımın en önemli yapı taşları arasında yer almaktadır. Çevresel değişkenleri anlık olarak takip edebilen sensörler aracılığıyla elde edilen veriler, yapay zekâ algoritmaları yardımıyla analiz edilmekte ve üreticiye karar desteği sunmaktadır. Ayrıca Coğrafi Bilgi Sistemi (CBS) ve Küresel Konumlandırma Sistemi (GPS) entegrasyonu ile konum bazlı veriler işlenerek detaylı haritalama ve uygulama planlaması yapılabilmektedir. Bu durum, hem verimliliği artırmakta hem de tarımsal girdilerin daha etkili ve çevreye duyarlı bir biçimde kullanılmasını mümkün kılmaktadır. Özellikle hassas tarım uygulamalarında bu teknolojiler, doğru zamanda, doğru miktarda ve doğru yere müdahale edilmesini sağlamaktadır.

Drone teknolojileri ise engebeli, eğimli ve erişimi zor alanlarda operasyonel kolaylık sağlaması bakımından önemli bir yenilik olarak öne çıkmaktadır. Havadan gerçekleştirilen gözlem, ilaçlama ve gübreleme faaliyetleri sayesinde insan gücüne olan ihtiyaç azalmış, buna karşılık işlem hassasiyeti artmıştır. Ayrıca, yapay zekâ tabanlı sistemlerin tam kapasite çalışabilmesi için büyük ve güvenilir veri setlerine duyduğu ihtiyaç, dijital tarımın altyapısal ve kurumsal gelişimine olan gereksinimi ortaya koymaktadır. Dolayısıyla, dijital tarımın yaygınlaştırılabilmesi için çiftçilerin dijital okuryazarlığının geliştirilmesi, teknik altyapının güçlendirilmesi ve kamu politikalarının bu dönüşümü destekleyecek şekilde düzenlenmesi gerekmektedir. Sonuç olarak, dijital tarım yalnızca teknolojik bir

https://www.dlg.org/en/mediacenter/alle-publikationen/strategische-positionspapiere/digital-agriculture-opportunities-risks-acceptance adresinden alındı

Dobrev, D. (2005). Formal definition of artificial intelligence. . *International Journal" Information Theories & Applications, 12(3)*, 277-285.

Göl, B., & Tarhan, Ç. (2024, Eylül 3). Tarımda Dijitalleşmenin Zorlukları ve AB İklim Politikasında Dijital Tarım. *Bilişim Sistemleri ve Yönetim Araştırmaları Dergisi*, s. 12-23.

Görmez, E., & Ertaş, N. (2019). Sosyal Bilgiler Öğretmenlerinin Küresel Konumlandırma Sistemi ve Coğrafi Bilgi Sistemleri Hakkındaki Görüşleri. *YYÜ Eğitim Fakültesi Dergisi 16(1)*, s. 1492-1514.

Gündüz, M., & Daş, R. (2018). Nesnelerin interneti: Gelişimi, bileşenleri ve uygulama alanları. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 24(2)*, s. 327-335.

İnan, M., & Karcı, A. (2021, Haziran 1). Tarımda Ağaç İlaçlamanın Drone'larla Yapılmasında Yeni bir Yöntemin Geliştirilmesi ve Uygulanması. *Anatolian Journal of Computer Sciences cilt: 6 (2)*, s. 72-89.

Javaid, M., Haleem, A., Khan, I. H., & Suman, R. (2023). Understanding the potential applications of Artificial Intelligence in Agriculture Sector. *Advanced Agrochem, 2(1)*, 15-30.

Kahveci, M., & Can, N. (2017, Ağustos 09). İnsansız hava araçları: tarihçesi, tanımı, dünyada ve türkiye'deki yasal durumu. *Selçuk Üniversitesi Mühendislik, Bilim ve Teknoloji Dergisi Cilt: 5 Sayı: 4*, s. 511-535.

Keogh, M., & Henry, M. (2016). The implications of digital agriculture and big data for Australian agriculture. *Australian Farm Institute.*

Keskin, M., Şekerli, Y. E., Say, S. M., & Arslan, A. (2018, Mayıs - Haziran). Hassas Tarım Teknolojileri İle Sağlanabilecek Faydalar. *Tarım Türk Dergisi Sayı: 30*, s. 14-17.

Kırçıl, U., & Tepe, C. (2024). İnsansız Kara Araçları İçin Çapraz Platform Destekli Telemetri Sistemi Tasarımı. *Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi* , s. 53-60.

Lake, B. M., Ullman, T. D., Tenenbaum, J. B., & Gershman, S. J. (2017). Building machines that learn and think like people. *Behavioral and brain sciences, 40*, e253.

Li, C., & Niu, B. (2020). Design of smart agriculture based on big data and Internet of things. . *International Journal of Distributed Sensor Networks, 16(5)*, 1550147720917065.

Mandal, D., & Ghosh, S. K. (2000). Precision farming–The emerging concept of agriculture for today and tomorrow. . *Current Science, 79(12)*, 1644-1647.

Martos, V., Ahmad, A., Cartujo, P., & Ordoñez, J. (2021). Ensuring agricultural sustainability through remote sensing in the era of agriculture 5.0. *Applied Sciences11 (13)*.

Mohsan, S., Khan, M. A., Noor, F., Ullah, I., & Alsharif, M. H. (2022). Towards the unmanned aerial vehicles (UAVs): A comprehensive review. *Drones, 6(6)*, 147.

Morik, K. (1991). Underlying assumptions of knowledge acquisition and machine learning. *Knowledge Acquisition, 3(2)*, 137-156.

Özgüven, M. M. (2023). *The digital age in agriculture.* CRC Press.

Öztürk, H., Eminoğlu, M. A., & Küçükyıldırım, H. (2025). Tarım Sektöründe Yapay Zeka: Uygulama Alanları ve Etkileri. İ. KAYA içinde, *Tarımda İnovasyon Ve Sürdürülebilirlik: Güncel Yaklaşimlar Ve Uygulamalar* (s. 3-25). Ankara: Iksad Publications.

Paraforos, D. S., & Griepentrog, H. W. (2021). Digital farming and field robotics: Internet of things, cloud computing, and big data. *Fundamentals of agricultural and field robotics*, 365-385.

Power, D. (2008). Decision Support Systems: A Historical Overview. P. Bernus, J. Blazewicz, G. Schmidt, & M. Shaw içinde, *In: Handbook on Decision Support Systems 1. International Handbooks Information System.* (s. 121-140). Berlin, Heidelberg: Springer.

Quebrajo, L., Pérez-Ruiz, M., Rodriguez-Lizana, A., & Agüera, J. (2015). An approach to precise nitrogen management using hand-held crop sensor measurements and winter wheat yield mapping in a mediterranean environment. *Sensors, 15(3)*, 5504-5517.

Rust, R. H., & Robert , P. (1980). A project to evaluate moisture stress in corn and soybean areas of western and southwestern Minnesota. *Minnesota Univ. A Study of Minn. Land and Water Resources Using Remote Sensing, Vol. 13.*, 89-98.

Sevli, O. (2023, Aralık 29). Tarım 4.0 ölçeğinde bir dijital tarım uygulaması: Çiftlik izleme ve yönetim sistemi. *Uluslararası Sürdürülebilir Mühendislik ve Teknoloji Dergisi 7(2),*, s. 105–116.

Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., & Carlsson, C. (2002). Past, present, and future of decision support technology. *Decision support systems, 33(2)*, 111-126.

Swanson, E. R. (1979). Working with other disciplines. *American Journal of Agricultural Economics, 61(5)*, 849-859.

Şahin, H. (2022, Temmuz 12). Dijital Tarım, Tarım 4.0, Akılı Tarım, Robotik Uygulamalar ve Otonom Sistemler . *Tarım Makinaları Bilimi Dergisi 18(2)*, s. 68-83.

Tantalaki, N., Souravlas, S., & Roumeliotis, M. (2019). Data-driven decision making in precision agriculture: The rise of big data in agricultural systems. *Journal of agricultural & food information, 20(4)*, 344-380.

Ünal, Z., & Kızıldeniz, T. (2023). Smart agriculture practices in potato production. M. M. Çalışkan içinde, *Potato Production Worldwide* (s. 317-329). Academic Press.

Velamuri, A. (2023). Data-Driven Management in Agriculture. In. Q. Zhang içinde, *Encyclopedia of Digital Agricultural Technologies* (s. 267-276). Springer International Publishing.

Walter, A., Finger, R., Huber, R., & Buchmann, N. (2017). Smart farming is key to developing sustainable agriculture. *Proceedings of the National Academy of Sciences, 114(24)*, 6148-6150.

Wang, H. (1997). ntelligent agent-assisted decision support systems: Integration of knowledge discovery, knowledge analysis, and group decision support.". *Expert Systems with Applications 12.3*, 323-335.

Zakota, A. (2024). Institutional Conditions for the Development of the Agricultural Industrial Complex in the Conditions of Digitization. *Innovations in Sustainable Agricultural Systems, Volume 2: ISAS 2024, 2*, 180.

Zhai, Z., Martínez, J., Beltran, V., & Martínez, N. (2020, March). Decision support systems for agriculture 4.0: Survey and challenges. *Computers and Electronics in Agriculture V: 170*.

Zhao, Y., Li, J., Li, L., Zhang, M., & Guo, L. (2013). Environmental perception and sensor data fusion for unmanned ground vehicle. *Mathematical Problems in Engineering, 2013(1)*, 903951.

Parkia biglobosa-a Tree of Food and Medicinal Values: Domesticate Them or Disappear

Aisha Idris Ali
Department of Food Science and Technology, Aliko Dangote University of Science and Technology Wudil

Corresponding author: aishaidrisali@gmail.com Tel: 08027545409

Abstract

Parkia biglobosa (African locust bean) is a culturally and nutritionally important tree species in West African agroforestry systems. Its fermented seeds (*soumbala*, *dawadawa*, *iru*) constitute a cornerstone protein condiment, while its pulp, bark, leaves, and pods provide food and traditional medicine. Despite its significance, *P. biglobosa* faces threats from land-use change, overexploitation, fire, grazing, and climate stress. Natural regeneration is poor, and domestication efforts remain limited, raising concern over its long-term survival. This review synthesizes current evidence on ethnobotany, nutritional composition, phytochemistry, pharmacology, ecology, and socio-economic importance. It also evaluates threats and outlines domestication pathways to secure both conservation and sustainable utilization. We argue that domestication, through farmer-led selection, propagation, pollinator-smart orchard management, and gender-equitable value-chain upgrading, offers the most viable strategy for future resilience. Without deliberate intervention, *P. biglobosa* risks gradual decline in populations and erosion of cultural heritage. With coordinated action, it can remain a pillar for food security, health, and livelihoods in West Africa.

Keywords: *Parkia biglobosa*, African locust bean, nutrition, ethnopharmacology, domestication, agroforestry, food security, conservation.

Introduction

Parkia biglobosa (Jacq.) R. Br. ex G. Don, also called the African locust bean tree, is widely distributed across the Sudano–Sahelian region (Teklehaimanot, 2004). It is co-managed with Vitellaria paradoxa in agroforestry parklands, where its products provide essential food, income, and ecosystem services (Bayala et al., 2003). Seeds are fermented into protein-rich condiments (soumbala, iru, dawadawa) (Termote et al., 2022). The pulp serves as a sweetener and energy source (Termote et al., 2022). Leaves, bark, and pods are integral to traditional medicine (Komolafe et al., 2014). However, pressures from agriculture, deforestation, and climate change threaten its survival (Plečková et al., 2024). This review synthesizes knowledge on the nutritional and medicinal values of *P. biglobosa*, evaluates challenges, and discusses domestication as a pathway for conservation and sustainable use.

Ethnobotany and Food Uses of *P. biglobosa*

P. biglobosa seeds are fermented into high-protein condiments (soumbala, iru, *dawadawa*) (Termote et al., 2022). Pulp is consumed fresh or processed into beverages (Termote et al., 2022). Foliage and pods are used as livestock feed (Teklehaimanot, 2004). Flowers are important nectar source for honey production (Jensen et al., 2017). Women play central roles in processing and marketing (Price et al., 2015).

Nutritional Composition

Table 1. Nutritional profile of *P. biglobosa* products (per 100 g dry weight)

Product	Protein	Lipids	Carbohydrates	Key Micronutrients	Notes
Raw seeds	30–35%	20–25%	30–40%	Iron, calcium, zinc	Presence of antinutrients (Samtiya et al., 2020)
Fermented seeds	35–40%	20–30%	20–25%	Bioactive peptides, improved digestibility	Fermentation reduces antinutrients (Price et al., 2015)
Pulp	5–10%	1–3%	70–80%	Vitamin C, carotenoids	Energy-rich, sweet flavor (Termote et al., 2022)

Phytochemistry and Pharmacology

Reported phytochemicals include tannins, saponins, flavonoids, alkaloids, triterpenoids, and polysaccharides (Komolafe et al., 2014). Pharmacological studies suggest antimicrobial, anti-inflammatory, antihypertensive, antidiabetic, and neuroprotective properties (Komolafe et al., 2014). However, most evidence derives from *in vitro* or rodent models, often at high doses, with limited clinical validation.

Table 2. Pharmacological properties of P. biglobosa extracts

Extract/Compound	Reported Activity	Model	Evidence Strength	Reference
Seed protein hydrolysates	Antihypertensive (ACE inhibition)	*In vitro*, rodent	Moderate	Komolafe et al., 2014
Bark extract	Antimicrobial, anti-inflammatory	*In vitro*, animal	Preliminary	Komolafe et al., 2014
Leaf extract	Antidiabetic (glucose lowering)	Rodent	Preliminary	Komolafe et al., 2014
Pulp extract	Antioxidant	*In vitro*	Moderate	Termote et al., 2022

Ecology and Threats

P. biglobosa is an outcrossing species reliant on bats and bees for pollination (Tinguely et al., 2012; Jensen et al., 2017). Natural regeneration is poor due to grazing, fire, and seed predation (Ræbild et al., 2012). Land conversion for agriculture and charcoal production further exacerbates population decline (Houndonougbo et al., 2020). Climate change is projected to shift its suitable ranges southward (Plečková et al., 2024). Pollinator declines due to habitat loss and pesticide exposure also threaten productivity (Jensen et al., 2017).

Table 3. Threats vs. Consequences for *P. biglobosa*

Threat	**Consequence**	**Reference**
Land-use change	Loss of habitat and mature trees	Houndonougbo et al., 2020
Overexploitation (bark, seeds)	Reduced regeneration capacity	Komolafe et al., 2014
Fire & grazing	High seedling mortality	Ræbild et al., 2012
Climate change	Range shifts, reduced productivity	Plečková et al., 2024
Pollinator decline	Lower pod and seed set	Jensen et al., 2017

Domestication Pathways

Domestication strategies include seed pre-treatment (scarification, hot water, acid) (Vinceti et al., 2013), vegetative propagation (grafting, cuttings), and breeding for traits such as seed size, ease of dehulling, fermentation quality, and drought tolerance (Teklehaimanot, 2004). Pollinator-smart orchards supporting bats and bees enhance productivity (Jensen et al., 2017). Seed systems with decentralized nurseries and quality control are essential (Houndonougbo et al., 2020).

Socio-Economic Importance and Gender

Women dominate processing and marketing but face challenges of land tenure, finance, and equipment (Price et al., 2015). Domestication and value-chain upgrading (e.g., mechanized dehullers, improved fermentation, shelf-stable condiments) should prioritize gender equity for maximum livelihood impact (Termote et al., 2022).

Policy and Governance

Policy interventions should secure tenure for women and smallholders (Houndonougbo et al., 2020), incentivize pollinator conservation (Jensen et al., 2017), and integrate P. biglobosa into climate adaptation and restoration programs (Plečková et al., 2024). Establishing food safety and quality standards for fermented products is also crucial (Price et al., 2015).

Conclusion

Parkia biglobosa embodies the dual role of food and medicine in West Africa. Without proactive domestication, populations will continue to decline under ecological and socio-economic pressures. With coordinated farmer-led domestication, pollinator conservation, and equitable value-chain development, *P. biglobosa* can remain central to nutrition, health, and livelihoods. Domestication is not optional it is essential for survival.

References

Bayala, J., Teklehaimanot, Z., & Ouédraogo, S. J. (2003). Effects of pruning on production of Vitellaria paradoxa and Parkia biglobosa and yield of associated crops in parklands. In Improved Management of Agroforestry Parkland Systems in Sub-Saharan Africa. EU/INCO Final Report.

Houndonougbo, J. S. H., Kassa, B., Mensah, S., Salako, V. K., & Assogbadjo, A. E. (2020). A global systematic review on conservation and domestication of Parkia biglobosa. Agroforestry Systems, 94(5), 1831–1847.

Jensen, K., et al. (2017). Honey bees ensure pollination of Parkia biglobosa in the absence of bats. Journal of Pollination Ecology, 20, 22–34.

Komolafe, E. A., et al. (2014). Phytochemical screening and bioactivity of Parkia biglobosa. Journal of Ethnopharmacology, 154(1), 87–93.

Plečková, K., et al. (2024). Past, present and future potential distributions of Parkia biglobosa under climate change. Plant Ecology and Evolution, 157(2), 164–176.

Price, R., et al. (2015). Towards the development of shelf-stable “iru” (P. biglobosa) fermented condiment. Food Research International, 76, 481–489.

Ræbild, A., Hansen, U. B., & Kambou, S. (2012). Regeneration of Vitellaria paradoxa and Parkia biglobosa in a parkland in southern Burkina Faso. Agroforestry Systems, 85(3), 443–453.

Samtiya, M., Aluko, R. E., & Dhewa, T. (2020). Plant food antinutrients: Trends and advances. Food Research International, 131, 109106.

Termote, C., Odongo, N. O., Dreyer, B. S., Guissou, B., Parkouda, C., & Vinceti, B. (2022). Nutrient composition of Parkia biglobosa pulp, raw and fermented seeds: A systematic review. Critical Reviews in Food Science and Nutrition, 62(1), 119–144.

Teklehaimanot, Z. (2004). Exploiting the potential of indigenous agroforestry trees: Parkia biglobosa and Vitellaria paradoxa. Agroforestry Systems, 61(1), 207–220.

Tinguely, L., et al. (2012). Bats and bees pollinate Parkia biglobosa in The Gambia. Agroforestry Systems, 85(3), 465–473.

Vinceti, B., et al. (2013). Agroforestry tree domestication: A primer. ICRAF Technical Manual.

Bioactive Compounds and Bioactivities of *Celtis Zenkeri* Leaves

Aisha Idris Ali

Department of Food Science and Technology, ADUSTECH, Wudil,

Corresponding author: aishaidrisali@gmail.com Tel: +2348027545409

Abstract

Celtis zenkeri Engl. (Cannabaceae), a deciduous West and Central African tree used in traditional medicine, has attracted growing phytochemical and pharmacological interest. Recent analyses reveal that leaf essential oil is dominated by the diterpene alcohol phytol (~46% of oil composition), and leaf extracts contain diverse non-volatile phenolics, flavonoids, tannins, terpenoids, and alkaloids. These constituents confer potent *in vitro* antioxidant activity, demonstrable antimicrobial and anti-inflammatory effects at extract/volatile levels, and promising antihyperglycaemic effects in preclinical models. Acute and subchronic toxicity screening suggests a favourable safety margin at tested doses, although comprehensive chronic and reproductive toxicology remain lacking. This review synthesizes current knowledge on the phytochemistry and bioactivities of *C. zenkeri* leaves, highlights mechanistic hypotheses for observed pharmacology, and identifies prioritized research needs to support development of nutraceuticals or phytotherapeutics from this species.

Keywords: *Celtis zenkeri, phytol, essential oil, antioxidant, antihyperglycaemic, phytochemistry, ethnomedicine*

Introduction

The genus *Celtis* (Cannabaceae) includes numerous species with a long history of ethnomedicinal use across Africa, Asia and Europe (Rashid et al., 2024). *Celtis zenkeri* Engl., commonly referred to as Zenker's hackberry or African *Celtis*, is widely distributed in West and Central African moist forests and is traditionally used to manage coughs, fevers, pain, wounds and gastrointestinal complaints (Rashid et al., 2024). Recent phytochemical and pharmacological studies focused on *C. zenkeri* leaves have reported notable volatile-oil profiles and bioactivities (Okpala et al., 2022; Ayoola et al., 2023; Okpala et al., 2021). Given increased interest in plant-derived antioxidants and functional nutraceuticals, a critical synthesis of the available evidence is timely. This manuscript summarizes the current phytochemical data for *C. zenkeri* leaves, reviews the principal bioactivities, and outlines research priorities for mechanistic and safety studies.

Botanical background and traditional uses

Celtis zenkeri is a medium-to-large deciduous tree that grows in moist lowland and gallery forests across West and Central Africa (Rashid et al., 2024; Useful Tropical Plants, n.d.). Traditional uses of *C. zenkeri* parts include decoctions of stem bark and leaves to treat coughs, arthritis, fever and wounds; wood and bark are employed in construction and folk remedies (Rashid et al., 2024; Useful Tropical Plants, n.d.). Ethnopharmacological reports across the Celtis genus broadly point to antimicrobial, antipyretic, analgesic and gastrointestinal applications, which have guided targeted phytochemical investigations of several species (Rashid et al., 2024).

Phytochemical composition of *C. zenkeri* leaves

Volatile constituents (essential oil)

Hydrodistillation and GC–MS of *C. zenkeri* leaf essential oil consistently identify phytol as the major volatile constituent, accounting for approximately 46% of the leaf oil in reported analyses (Okpala et al., 2022). Phytol (a diterpene alcohol derived from chlorophyll side chains) is known for antioxidant and various bioactive properties and likely contributes substantially to the oil's radical scavenging capacity (Okpala et al., 2022; Rashid et al., 2024).

Nonvolatile phytochemicals

Although detailed, high-resolution metabolomic studies on *C. zenkeri* leaves remain limited, genus-wide reviews and screening of *C. zenkeri* extracts report the presence of phenolics, flavonoids, tannins, saponins, alkaloids, terpenoids and sterols, chemical classes that typically underpin antioxidant, anti-inflammatory and antimicrobial activity (Rashid et al., 2024; Ayoola et al., 2023; 2024; Oyedeji et al., 2021). The broader *Celtis* phytochemical inventory includes flavonols (quercetin, kaempferol derivatives), hydroxycinnamic acid derivatives, and diverse terpenoids, suggesting a comparable leaf profile in *C. zenkeri* pending full LC–MS/MS characterisation (Rashid et al., 2024). The reported bioactive compounds of Celtis zenkeri leaves and associated bioactivities is showed in Table 1.

Documented bioactivities of C. zenkeri leaf extracts and essential oil

Antioxidant activity

Leaf essential oil of *C. zenkeri* demonstrates strong in vitro antioxidant activity: DPPH radical-scavenging assays reported ~89% inhibition at 250 µg/mL for the leaf oil—values comparable to ascorbic acid and butylated hydroxyanisole at the same concentration (Okpala et al., 2022; Okpala et al., 2021; Oyedeji et al., 2020). Given the predominance of phytol and the presence of phenolic compounds in extracts, both volatile and nonvolatile constituents likely act in concert to confer antioxidative effects.

Antimicrobial activity

Although direct, peer-reviewed antimicrobial studies of *C. zenkeri* leaves are fewer than antioxidant reports, volatile and solvent extracts from *Celtis* species show antibacterial and antifungal activity against a range of pathogens (Rashid et al., 2024; Tchoumbougnang et al., 2019). Preliminary volatile-oil screens of *C. zenkeri* roots and leaves indicate *in vitro* inhibitory activity against selected microbes, supporting traditional uses for treating wounds and infections (Okpala et al., 2022; Okpala et al., 2021; Ayoola et al., 2023; Oyedeji et al., 2020).

Antidiabetic and enzyme-inhibitory effects

Ayoola et al., (2023) evaluated the antihyperglycaemic potential and safety of *C. zenkeri* leaf extract in rodent models. The extract reduced blood glucose levels, showed inhibitory activity against carbohydrate-hydrolysing enzymes (α-amylase and α-glucosidase) in vitro, and produced glucose-lowering effects comparable to reference antidiabetic agents in their study, without causing significant adverse haematological, hepatic or renal effects at tested doses (Ayoola et al., 2023; Folarin et al., 2021; Bello et al., 2020). These findings support folkloric antidiabetic uses and warrant mechanistic confirmation.

Anti-inflammatory and other effects

Genus-level studies identify anti-inflammatory, analgesic and cytotoxic potentials for several Celtis species (Rashid et al., 2024). Limited data for *C. zenkeri* leaf extracts indicate anti-inflammatory potential consistent with the presence of terpenoids and phenolics; however, focused pharmacodynamic investigations (e.g., cytokine profiling, COX/LOX inhibition assays) have not yet been reported for this species.

Mechanistic considerations

The observed antioxidant activity is plausibly related to free radical scavenging by phytol and phenolic constituents and by redox-active flavonoids. Antimicrobial effects may derive from membrane-active terpenoids and phenolics that disrupt microbial cell walls or interfere with essential enzymes. The antihyperglycaemic actions reported (enzyme inhibition and glucose lowering) are consistent with polyphenol-mediated inhibition of carbohydrate-digesting enzymes and possible enhancement of peripheral glucose uptake; however, specific molecular targets remain to be validated experimentally (Ayoola et al., 2023; Rashid et al., 2024; Okpala et al., 2022).

Safety and toxicology

Preliminary safety data from acute and sub-acute studies of *C. zenkeri* leaf extract indicate a high LD_{50} and no significant perturbations of routine biochemical or haematological markers at the doses tested in rodents (Ayoola et al., 2023). Nonetheless, the current toxicological evidence is incomplete: chronic toxicity, reproductive and developmental toxicity, genotoxicity and detailed dose-response evaluations have not been reported. Given the biological potency of certain constituents (e.g., phytol at high doses has recognized biological activities), rigorous toxicological profiling is a priority before recommending human use (Ayoola et al., 2023; Okpala et al., 2022; Adeniji et al., 2020; Bello et al., 2020). Table 2 showed the quantitative phytochemical contents and bioactivities of *Celtis zenkeri* leaves while Table 3 showed the comparison of phytochemical profiles and reported bioactivities across *Celtis* species.

Knowledge gaps and research priorities

Despite encouraging initial data, several critical knowledge gaps remain:

Comprehensive phytochemical profiling

Systematic LC–MS/MS, GC–MS (for volatiles), and NMR studies are needed to fully characterise both major and minor constituents in leaf extracts and essential oils (Rashid et al., 2024). Quantitative data (e.g., mg/g dry weight of phytol and representative flavonoids) will support dose standardisation.

Bioactivity-guided fractionation

Isolation and structural identification of active compounds responsible for antihyperglycaemic, antimicrobial and antioxidant effects are required to clarify mechanisms and identify lead molecules for development.

Mechanistic pharmacology

Targeted in vitro and in vivo studies should test hypotheses generated from primary screens (e.g., enzyme inhibition kinetics, insulin-signalling modulation, anti-inflammatory cytokine profiling).

Safety and ADME profiling

Standardised toxicology (chronic, reproductive, genotoxicity), as well as absorption, distribution, metabolism and excretion (ADME) studies, are required to de-risk clinical translation.

Standardisation and formulation development

If development as a nutraceutical is envisaged, standardised extract preparation and stability studies are necessary, including assessment of the contribution of essential oils versus polar extracts.

Conclusion

Leaves of *Celtis zenkeri* are a rich source of bioactive phytochemicals, notably phytol in the essential oil, and display a spectrum of *in vitro* and *in vivo* activities; antioxidant, antimicrobial, anti-inflammatory and antihyperglycaemic that help rationalise traditional uses. Preliminary safety data are reassuring, but extensive phytochemical, mechanistic and toxicological studies are needed to fully characterise therapeutic potential and support clinical translation. Given the widespread ethnopharmacological relevance of *Celtis* species, *C. zenkeri* represents a promising candidate for further natural-product research and nutraceutical development.

Table 1. Reported bioactive compounds of Celtis zenkeri leaves and associated bioactivities

Compound/Class	Specific examples reported	% composition / presence	Reported bioactivities	References
Diterpene alcohol	Phytol	~46% of leaf essential oil	Potent antioxidant, antimicrobial, anti-inflammatory, cytotoxic, antidiabetic (via enzyme inhibition)	Okpala et al., (2022)
Phenolics	Total phenolic content (not yet fully characterised)	Present in ethanolic/methanolic extracts	Antioxidant (radical scavenging), enzyme inhibitory	Ayoola et al., (2023); Rashid et al. (2024)
Flavonoids	Quercetin, kaempferol derivatives (reported in Celtis genus; inferred in C. zenkeri)	Detected in methanol extracts (qualitative)	Antioxidant, anti-inflammatory, antihyperglycaemic (enzyme inhibition, insulin sensitisation)	Rashid et al. (2024)
Tannins	Condensed tannins (leaf extracts)	Moderate levels reported	Antioxidant, antimicrobial, enzyme inhibitory, potential anti-diarrhoeal	Ayoola et al., (2023); Rashid et al. (2024)
Saponins	Triterpenoid saponins (qualitative detection)	Present in ethanolic extracts	Membrane-permeabilising antimicrobial activity, hypocholesterolaemic	Ayoola et al., (2023)
Alkaloids	Unspecified alkaloids (preliminary phytochemical screening)	Detected in leaf extracts	Analgesic, antimicrobial, enzyme modulation (general for alkaloids)	Ayoola et al., (2023); Rashid et al. (2024)
Sterols/Terpenoids	β-sitosterol, triterpenes (reported in Celtis genus)	Not yet quantified in C. zenkeri	Anti-inflammatory, cytotoxic, antioxidant	Rashid et al. (2024)

Table 2. Quantitative phytochemical contents and bioactivities of Celtis zenkeri leaves

Parameter	Reported value(s)	Method / assay	Reported bioactivities	References
Essential oil major component (phytol)	~46.28% of total essential oil	GC–MS analysis	Strong antioxidant activity; antimicrobial; cytotoxic; antidiabetic potential	Okpala et al., (2022)
Total phenolic content	58.3 ± 2.4 mg GAE/g dry extract (methanol extract)	Folin–Ciocalteu assay	Antioxidant, anti-inflammatory, enzyme inhibitory	Ayoola et al., (2023)
Total flavonoid content	21.7 ± 1.6 mg QE/g dry extract	Aluminium chloride colorimetric assay	Antioxidant, antidiabetic (enzyme inhibition)	Ayoola et al., (2023)
Tannins	12.5 ± 1.3 mg TAE/g dry extract	Folin–Denis assay	Antioxidant, antimicrobial, anti-diarrhoeal	Ayoola et al., (2023)
Saponins	8.2 ± 0.9 mg DE/g extract	Spectrophotometric assay	Antimicrobial, membrane disruption, cholesterol-lowering	Ayoola et al., (2023)
Alkaloids	9.6 ± 0.8 % (w/w, crude content in extract)	Gravimetric/acid–base extraction	Antimicrobial, analgesic, enzyme modulation	Ayoola et al., (2023)
Antioxidant activity (DPPH scavenging)	89.1% inhibition at 250 µg/mL (oil) vs. 92% for ascorbic acid	DPPH assay	Potent antioxidant	Okpala et al. (2022)
Antioxidant activity (FRAP assay)	451 µM Fe^{2+} equivalents/g extract	FRAP assay	Strong reducing power	Ayoola et al., (2023)
α-Amylase inhibition (antidiabetic)	IC_{50} = 39.2 µg/mL (extract)	In vitro α-amylase inhibition	Delays carbohydrate digestion; antihyperglycaemic	Ayoola et al., (2023)
α-Glucosidase inhibition	IC_{50} = 42.8 µg/mL (extract)	In vitro α-glucosidase inhibition	Reduces postprandial glucose absorption	Ayoola et al., (2023)
In vivo antihyperglycaemic effect	Decrease fasting blood glucose by 34% (200 mg/kg in alloxan-induced diabetic rats, 14 days)	Animal model	Significant glucose-lowering effect	Ayoola et al., (2023)

Table 3. Comparison of phytochemical profiles and reported bioactivities across Celtis species

Species	Major reported phytochemical classes	Quantitative / notable constituents (if reported)	Principal reported bioactivities	Key references / notes
Celtis zenkeri	Phytol-rich essential oil (terpenoids), phenolics, flavonoids, tannins, saponins, alkaloids, sterols	Phytol ≈ 46% of leaf essential oil; TPC ≈ 58.3 mg GAE/g; TFC ≈ 21.7 mg QE/g (methanol extract). α-Amylase IC_{50} ≈ 39.2 µg/mL; α-glucosidase IC_{50} ≈ 42.8 µg/mL.	Antioxidant (strong DPPH activity), antimicrobial (preliminary), anti-inflammatory (limited data), antihyperglycaemic (enzyme inhibition and in vivo glucose lowering); favourable acute safety profile.	Okpala et al., (2022); Ayoola et al., (2023); Okpala et al., (2021).
Celtis integrifolia	Phenolics, flavonoids, terpenoids, sterols (leaf extracts)	Quantitative reports limited; studies report measurable TPC and antioxidant capacity (varies by extraction).	Antioxidant, general pharmacognostic properties (leaf studies report free-radical scavenging and phytochemical content).	Rashid et al. (2024)
Celtis australis	Phenolic acids, flavonoids, triterpenes (bark and leaf literature)	Several isolated flavonoids and triterpenoids reported in the literature (amounts vary by study).	Antioxidant, antimicrobial, anti-inflammatory, occasional cytotoxic screening hits.	Rashid et al. (2024).
Celtis africana	Flavonoids, phenolics, tannins, terpenoids (leaf and bark)	Qualitative/semiquantitative phytochemical screens reported; few standardized quantitative assays.	Antimicrobial, wound-healing activity in ethnomedicinal studies; antioxidant activity in extract screens.	Rashid et al. (2024).
Celtis occidentalis	Phenolics, flavonoids, sterols (wood/leaf studies)	Phytochemical classes documented; variable TPC/TFC values reported across studies.	Antioxidant and antimicrobial activity reported in screening studies.	Rashid et al. (2024).

References

Ayoola, M. D., Odediran, A. S., Famuyiwa, S. O., Oluwagbemi, M., Afolabi, L. I., Oladoja, F. A., & Kasumu, O. E. (2023). Evaluation of the antihyperglycaemic activities, safety and phytochemical profile of Celtis zenkeri Engl. Archives of Pharmacy & Pharmaceutical Sciences, 7, 036–044. https://doi.org/10.29328/journal.apps.1001042

(Full text / PDF: https://www.pharmacyscijournal.com/apdf/apps-aid1042.pdf)

Adeniji, A. J., Adewale, O. B., Adekeye, B. T., Adekoya, A. O., Adeniji, O. B., & Ajayi, A. M. (2020). In vitro cytotoxicity and apoptotic effect of Celtis zenkeri leaf extract against MCF-7 human breast cancer cell line. Journal of Medicinal Plants for Economic Development, 4(1), 1–9.

Bello, O. I., Ayoola, M. D., Obembe, O., & Akinwunmi, K. F. (2020). Antidiabetic and toxicity studies of the extract of four Nigerian medicinal plants. European Journal of Medicinal Plants, 33(11), 32–45.

Folarin, R. O., Alade, G. O., Olorunsogo, O. O., & Oridupa, O. A. (2021). Antidiabetic and hypolipidemic effect of methanol extract of Celtis zenkeri leaves in streptozotocin-induced diabetic rats. South African Journal of Botany, 140, 206–211.

Okpala, E. O., Onocha, P. A., & Ali, M. S. (2022). Antioxidant activity of phytol-dominated stem bark and leaf essential oils of Celtis zenkeri Engl. Trends in Phytochemical Research, 6(2), 137–144. https://oiccpress.com/tpr/article/view/11823

Okpala, E. O., Onocha, P. A., Ali, M. S., Ur-Rehmen, S. Z., & Lateef, M. (2021). Zenkeramide: A new iso-benzofuranone propanamide and urease-inhibitory constituents of Celtis zenkeri Engl. stem bark. Natural Product Research, 37(1), 93–98. https://doi.org/10.1080/14786419.2021.1954643

Oyedeji, A. O., Adeyemi, O. A., Aremu, O. J., & Afolayan, A. J. (2020). Evaluation of phytochemical composition, antioxidant and antimicrobial activities of Celtis zenkeri. Journal of Medicinal Plants Research, 14(2), 63.

Rashid, M. A., Samadd, M. A., Hossain, J., Zahan, S., Islam, M. M., & Rashid, M. A. (2024). A comprehensive account on ethnobotany, phytochemistry and pharmacological insights of genus Celtis. Heliyon, 10(9), e29707. https://doi.org/10.1016/j.heliyon.2024.e29707

Tchoumbougnang, F., Ekué, M. R. M., Mapongmetsem, P. M., & Wouatsa, N. A. (2019). Antifungal activity of extracts of bark from Celtis zenkeri. International Journal of Microbiology and Mycology, 8(4), 396–402.

Useful Tropical Plants. (n.d.). Celtis zenkeri — Useful Tropical Plants Database. Retrieved September 10, 2025, from https://tropical.theferns.info/viewtropical.php?id=Celtis+zenkeri

(Article page / journal record: https://sanad.iau.ir/Journal/tpr/Article/874047; preserved copy: https://sid.ir/en/Journal/ViewPaper.aspx?ID=550066)

Tarımda Dijital Teknolojiler Ve Kullanımının Önemi

Zeki Bayramoğlu[1,*]

[1]Selçuk Üniversitesi, Ziraat Fakültesi, Tarım Ekonomisi Bölümü, Konya, Türkiye

zbayramoglu@selcuk.edu.tr ORCID: 0000-0003-3258-3848

Özet

Bu çalışmanın amacı, küresel ölçekte artan iklimsel, ekonomik ve sosyal risklerin tarımsal üretim üzerindeki baskılarını ele alarak dijital tarım teknolojilerinin önemini bütüncül biçimde değerlendirmektir. Nüfus artışı, iklim değişikliği, girdi maliyetlerindeki yükseliş, su kıtlığı ve tarım işletmelerinin yapısal sorunları; geleneksel üretim modellerinin sürdürülebilirliğini zayıflatmaktadır. Bu bağlamda dijital tarım, sensörler, uydu ve drone tabanlı izleme sistemleri, yapay zekâ, büyük veri analitiği ve blockchain gibi teknolojilere dayanan yeni bir üretim paradigması ortaya koymaktadır. Çalışmada dijital teknolojiler düşük, orta ve yüksek teknoloji seviyelerinde sınıflandırılmış; bu teknolojilerin verim, su kullanımı, girdi tasarrufu, ürün kalitesi, izlenebilirlik, çevresel performans ve çiftçi geliri üzerindeki etkileri uluslararası bulgularla desteklenmiştir. Ayrıca Türkiye'de dijital tarımın geliştirilebilmesi için altyapı, su yönetimi, veri entegrasyonu, yapay zekâ uygulamaları, sensör tabanlı hayvancılık, izlenebilirlik sistemleri ve kamu–üniversite–özel sektör işbirliğine yönelik politika önerileri sunulmuştur. Sonuç olarak dijital tarım, hem küresel risklerle mücadele hem de sürdürülebilir üretim modellerinin geliştirilmesi açısından stratejik bir zorunluluk olarak değerlendirilmektedir.

Anahtar Kelimeler: *Dijital Tarım, Tarımsal Sürdürülebilirlik, İklim Adaptasyonu, Gıda Güvenliği, Tarım Politikası*

Abstract

This paper provides a comprehensive assessment of the growing importance of digital agriculture in the face of increasing climatic, economic, and social pressures on global food systems. Population growth, climate change, rising input costs, water scarcity, and structural constraints in agricultural enterprises undermine the sustainability of traditional production models. In this context, digital agriculture represents a new production paradigm based on technologies such as sensors, satellite and drone-based monitoring, artificial intelligence, big data analytics, and blockchain. Digital technologies are classified into low, medium, and high levels, and their effects on productivity, water use efficiency, input savings, product quality, traceability, environmental performance, and farm income are discussed using global evidence. The study further offers policy recommendations for Türkiye, focusing on digital infrastructure, smart irrigation, data integration, AI-driven decision support, sensor-based livestock systems, blockchain-enabled traceability, and multi-stakeholder collaboration. Overall, the findings indicate that digital agriculture is not merely an option but a strategic necessity for enhancing resilience, food security, and sustainable agricultural production.

Key Words: *Digital Agriculture, Agricultural Sustainability, Climate Adaptation, Food Security, Agricultural Policy*

Giriş: Tarımda Dijitalleşmenin Artan Önemi

Tarım, küresel ölçekte ekonomik faaliyet alanı olmakla birlikte aynı zamanda ülkelerin siyasal bağımsızlığını, toplumsal istikrarını ve gelecek kuşakların yaşam güvencesini belirleyen stratejik bir sektördür. Dünya nüfusu 2024 itibarıyla 8,1 milyara ulaşmış ve gıda talebi hızla artmaya devam etmiştir (UN DESA, 2024). Buna karşın, kişi başına düşen ekilebilir arazi miktarında azalmalar olmuş, küresel ölçekte tarımsal üretim üzerinde ciddi baskılar oluşmuştur. Böyle bir ortamda dijital tarım teknolojileri, üretim sürecini daha rasyonel, izlenebilir, verimli ve sürdürülebilir hâle getiren önemli bir dönüşüm aracı hâline gelmiştir.

Dijitalleşmenin tarımsal üretimle ilişkilendirilmesinin temelinde, insan davranışlarını açıklayan psikoloji kuramlarından biri olan Maslow'un ihtiyaçlar hiyerarşisi yer alır. Maslow'a göre beslenme, barınma ve güvenlik gibi temel fizyolojik gereksinimler, tüm diğer ihtiyaçların önünde gelir. Gıda, hiyerarşinin en alt basamağını oluşturduğu için toplumların sürdürülebilirliğini doğrudan belirler (Maslow, 1943). Bu nedenle modern tarım sistemlerinde üretimin sürekliliği, verimliliği ve güvenilirliği artık yalnızca ekonomik bir mesele değil, aynı zamanda insani bir zorunluluktur. Tarımda dijitalleşme; su, toprak, enerji ve işgücü gibi kıt kaynakları daha etkin kullanmayı sağlayarak toplumların en temel ihtiyacının sürdürülebilir biçimde karşılanmasına katkı sunmaktadır.

Küresel gıda güvenliği son yıllarda daha da kırılgan hâle gelmiştir. Dünya nüfusunun bir bölümü açlık riski altında ve göç nedeniyle düzenli gıdaya erişememektedir (FAO, 2025). Ayrıca 2024 yılı, modern kayıtların tutulduğu tarihten bu yana "en sıcak yıl" olarak kaydedilmiş; IPCC verilerine göre 2025–2029 arasında 1,5°C ısınma eşiğinin aşılma ihtimali %80'e yükselmiştir (IPCC, 2024). Sıcaklık artışı buğday veriminde %6, mısırda %7,4, pirinçte %3,2 ve soyada %3,1 oranında kayıp riskini artırmaktadır. Bu eğilim, tarımsal üretimin geleceğini doğrudan tehdit ederken dijital tarım teknolojilerine olan ihtiyacı daha görünür kılmaktadır.

Dünya nüfusu artarken tarım alanlarının daralması, sektörün dijital teknoloji kullanımını zorunlu kılan diğer önemli faktörlerden biridir. FAO'nun arazi istatistiklerine göre bazı ülkelerde tarım alanları son on yılda %10'un üzerinde daralırken, diğer taraftan tarımsal girdilerdeki fiyat artışları maliyetleri ağırlaştırmaktadır. 2025 yılı itibarıyla dünya gübre fiyatları TSP'de %43, DAP'ta %23 artış göstermiş; navlun fiyatları ise Süveyş ve Panama geçişlerindeki sorunlar nedeniyle tarihsel ortalamaların çok üzerine çıkmıştır (World Bank, 2025). Tarım alanları azalırken üretimin sürdürülebilmesi için birim alanda daha yüksek verim alınması gerekmektedir. Bu zorunluluk, sensör tabanlı sulama, yapay zekâ destekli verim tahmini, dronlarla görüntüleme ve otomatik gübreleme gibi dijital teknolojilerin hızla yaygınlaşmasına yol açmaktadır.

Genel olarak küresel eğilimler değerlendirildiğinde tarım sektörü, hem biyofiziksel hem de sosyoekonomik baskıların yoğun olduğu bir döneme girmiştir. Nüfus artışı, iklim değişikliği, girdi maliyetlerindeki yükseliş ve arazi kayıpları tarımsal üretimi daha karmaşık hâle getirmektedir. Bu nedenle dijitalleşme, tarımı geleceğe hazırlayan stratejik bir zorunluluk olarak ortaya çıkmaktadır. Veri odaklı karar verme süreçleri, otomasyon, yapay zekâ, sensör teknolojileri ve blockchain tabanlı izlenebilirlik uygulamaları, yalnızca üretim verimliliğini artırmakla kalmamakta; aynı zamanda gıda güvenliği, sürdürülebilirlik ve kırsal kalkınma açısından yeni fırsatlar yaratmaktadır.

Küresel Ölçekte Tarımı Tehdit Eden Riskler

Küresel ölçekte tarımsal üretim, iklim değişikliği, ekonomik dalgalanmalar, sosyal dönüşümler ve demografik baskılar nedeniyle tarihinin en kırılgan dönemlerinden birinden geçmektedir. Birleşmiş Milletler Gıda ve Tarım Örgütü (FAO), 2025 yılında dünya genelinde 673 milyon insanın açlık riski altında olduğunu ve gıda güvencesizliğinin özellikle iklimsel şoklarla birlikte hızla arttığını belirtmektedir (FAO, 2025). Artan sıcaklıklar, su kıtlığı, girdi maliyetleri, enerji fiyatlarındaki dalgalanmalar ve göç hareketleri tarım sektörünü doğrudan etkilemekte; üretim miktarını, verim düzeyini ve tarımsal tedarik zincirlerini tehdit etmektedir. Ayrıca 2024 yılının modern ölçümlerin başladığı tarihten bu yana en sıcak yıl olarak kaydedilmesi, tarım sektörü üzerindeki baskının boyutunu daha da görünür hâle getirmiştir (World Meteorological Organization [WMO], 2024).

İklimsel Riskler

İklim değişikliği, tarımsal üretim için en kritik risk alanıdır. WMO'nun 2024 raporuna göre okyanus ısıları rekor seviyeye ulaşmış, küresel sıcaklık artışı 1850–1900 ortalamasına göre 1,45°C dereceye yaklaşmıştır. 2025–2029 döneminde 1,5°C eşiğinin aşılma olasılığı %80 olarak hesaplanmaktadır (WMO, 2024). Bu sıcaklık artışı özellikle buğday, mısır, pirinç ve soya gibi temel gıda ürünlerinde ciddi verim kayıplarına yol açmaktadır. Her +1°C sıcaklık artışı, buğdayda %6, mısırda %7,4, pirinçte %3,2 ve soyada %3,1 oranında verim azalmasına neden olmaktadır (FAO, 2025).

Kuraklık, sıcak dalgaları, ani yağışlar ve sel gibi uç hava olayları da tarım sektöründe üretim kayıplarını artırmaktadır. IPCC, özellikle Akdeniz Havzası'nı dünyanın en kırılgan bölgelerinden biri olarak tanımlamakta ve bu bölgede uzayan kuraklık dönemleri, su kıtlığı ve aşırı sıcak dalgalarının daha sık görüleceğini belirtmektedir (IPCC, 2023). Su kıtlığı da tarımsal üretimi tehdit eden diğer bir önemli faktördür; çünkü dünya genelinde tatlı su kullanımının %70'den fazlası tarımsal sulamada yoğunlaşmaktadır.

Bu veriler, iklimsel risklerin yalnızca üretim miktarını azaltmakla kalmadığını; aynı zamanda üretim maliyetlerini artırarak tarımın sürdürülebilirliğini de olumsuz etkilediğini göstermektedir.

Ekonomik Riskler

Küresel tarım ekonomisi, girdi fiyatlarındaki istikrarsızlık, enerji maliyetlerinin artışı, döviz kuru dalgalanmaları, navlun fiyatlarındaki yükseliş ve jeopolitik gelişmeler nedeniyle ciddi baskı altındadır. FAO'nun 2025 Gıda Fiyat Endeksi, önceki yıla göre %7,6 artış göstererek 130,1 puana yükselmiştir (FAO, 2025). Özellikle gübre fiyatları dünya genelinde çiftçiler üzerinde büyük baskı yaratmaktadır: TSP fiyatları %43, DAP fiyatları ise %23 artmıştır.

Ayrıca, Süveyş Kanalı ve Panama Kanalı gibi kritik ticaret güzergâhlarında yaşanan aksaklıklar navlun fiyatlarını yükselterek tarımsal ürünlerin lojistik maliyetlerini artırmaktadır. Hindistan'ın pirinç ihracatına getirdiği sınırlamalar ise küresel gıda fiyatlarında zincirleme bir etkiye neden olmuş; pek çok ülke için kritik arz sorunları ortaya çıkarmıştır (World Bank, 2025).

Enerji fiyatlarındaki artış; sulama, gübre üretimi, depolama ve ulaşım maliyetlerini doğrudan yukarı çekmektedir. Birçok ülkede tarımsal işçilik maliyetlerinde yıllık artış oranları %50'nin üzerine çıkmış; bu durum özellikle gelişmekte olan ülkelerde üretim maliyetlerini daha da yükseltmiştir. Ekonomik risklerin bu boyutu, tarım sektörünün kırılganlığını artırmakta ve çiftçilerin üretimden çekilmesine zemin hazırlamaktadır.

Sosyal ve Demografik Riskler

Küresel ölçekte tarımı tehdit eden bir diğer önemli alan sosyal ve demografik değişimlerdir. Dünya genelinde kırsal nüfus hızla yaşlanmakta, tarım sektöründe genç işgücü oranı düşmekte ve kırsaldan kentlere göç artmaktadır. FAO'ya göre dünya genelinde 123,2 milyon kişi zorunlu göçmen durumundadır ve bu kitlesel hareketler özellikle tarımsal işgücü arzında istikrarsızlık yaratmaktadır (FAO, 2025).

Birçok ülkede tarım işletmeleri küçük ölçekli ve parçalı yapıda olduğu için modern tarım tekniklerinin uygulanması zorlaşmakta; verim düşüklüğü ve rekabet gücü kayıpları yaşanmaktadır. Tarımsal arazilerin miras yoluyla bölünmesi, üretim yapılarını daha kırılgan hâle getirmekte ve işletme başına düşen arazi miktarını azaltmaktadır. Bunun yanında çiftçilerin dijital okuryazarlık ve teknoloji kullanım düzeylerinin yetersiz olması, dijital tarım uygulamalarının yaygınlaşmasını sınırlayan başka bir sosyal risktir.

Ayrıca savaş, iç çatışma ve siyasi istikrarsızlık gibi faktörler, özellikle Afrika ve Orta Doğu'da tarım sektörünü derinden etkilemekte; üretim alanlarının tahrip olmasına, girdi tedarikinde kesintilere ve kırsal yoksulluğun artmasına neden olmaktadır. Bu sosyal ve demografik baskılar, küresel tarımın sürdürülebilirliği için önemli tehdit unsurlarıdır.

Dijital Tarım Teknolojileri ve Sınıflandırılması

Dijital tarım teknolojileri, bilgi ve iletişim teknolojileri, sensörler, uydu ve drone tabanlı uzaktan algılama, yapay zekâ, büyük veri analitiği ve blokzincir gibi araçların tarımsal üretim, lojistik ve pazarlama süreçlerine entegre edilmesini ifade etmektedir (FAO, 2019; Trendov, Varas & Zeng, 2019). Bu teknolojiler, klasik mekanizasyonun ötesine geçerek tarladan sofraya uzanan değer zincirinin tamamında veri temelli karar alma, izlenebilirlik, kaynak verimliliği ve sürdürülebilirlik hedeflerine hizmet etmektedir (FAO, 2023; OECD, 2022). Ancak pratikte, hala dijital tarım teknolojilerinin gelişim süreci devam etmektedir. OECD'nin "The Digitalisation of Agriculture" raporu, özellikle sıra bitkileri üretiminde dijital teknolojilerin yaygınlaşmasına rağmen küresel ölçekte dönüşümün henüz olgunlaşmadığını belirtir (OECD, 2022). Avrupa Birliği Konseyi'nin 2024 tarihli değerlendirmesi, dijital tarım pazarının 2023 itibarıyla yaklaşık 24,91 milyar USD büyüklüğe ulaştığını ve 2030'da 71,48 milyar USD'ye çıkmasının öngörüldüğünü; bu genişlemenin %16,3'lük bir bileşik büyüme oranına işaret ettiğini ifade etmektedir (Consilium, 2024). Benzer biçimde Global Market Insights verileri, 2023 yılında dijital tarım pazarının 22 milyar USD'yi aştığını ve 2032 yılında 57 milyar USD seviyesine yükselebileceğini, bu süreçte yıllık büyüme hızının %11'in üzerinde seyrettiğini rapor etmiştir (Global Market Insights, 2024). Dünya Bankası'nın "Data-Driven Digital Agriculture" çalışması ise dünya genelinde yaklaşık 570 milyon çiftliğin bulunduğunu ve bu çiftliklerin veri temelli dijital teknolojilere entegrasyonunun üretkenliği yükseltip gıda güvensizliği ile eşitsizlikleri azaltabileceğini vurgulamaktadır (World Bank, 2023).

FAO ve Dünya Bankası'nın son raporlarında, dijital tarımın üretkenliği artırırken aynı zamanda gıda güvenliği, iklim değişikliğine uyum ve kırsal yoksulluğun azaltılması açısından kritik bir dönüşüm aracı hâline geldiği vurgulanmaktadır (FAO, 2022; World Bank, 2019). Ancak bu teknolojilerin tek tip olmadığı; basit veri toplama sistemlerinden, tam otomatik ve yapay zekâ destekli üretim modellerine uzanan bir yelpaze oluşturduğu görülmektedir (Abiri, ve ark., 2023; Sonka, 2020).

Bu nedenle literatürde dijital tarım teknolojileri, düşük, düşük–orta, orta–yüksek ve yüksek teknoloji olmak üzere kademeli bir sınıflandırma ile ele alınmakta; her düzey hem teknik karmaşıklık hem de veri yoğunluğu ve karar destek kapasitesi açısından birbirinden ayrılmaktadır (FAO, 2019; FAO, 2023). Aşağıda bu sınıflandırma, dünyadan örnekler ve somut uygulama alanlarıyla birlikte açıklanmaktadır.

Düşük Teknoloji Uygulamaları

Düşük teknoloji düzeyi, çoğunlukla mevcut mekanizasyon altyapısına basit dijital bileşenlerin eklenmesiyle oluşan, veri toplama ve temel izleme işlevlerine odaklanan çözümleri kapsamaktadır. Bu kategoride;

basit toprak nem sensörleri,

temel hava durumu istasyonları,

GPS ile konum kaydı yapan el terminalleri,

Çiftlik faaliyetlerini kayıt altına alan mobil uygulamalar gibi sistemler yer almaktadır (Trendov et al., 2019; FAO, 2022).

Bu teknolojilerin temel amacı, küçük ölçekli işletmelerin dijital dönüşüme düşük maliyetle adım atmasını sağlamak ve üretici davranışını veri temelli hâle getirmektir. Örneğin Afrika ve Asya'da yaygınlaşan mobil tarım uygulamaları, çiftçilere hava durumu tahmini, fiyat bilgisi ve basit kayıt tutma imkânı sağlayarak verimlilik ve gelir artışına katkı sunmaktadır (FAO, 2022; World Bank, 2019). Bu düzeyde veri analizi çoğunlukla tanımlayıcı istatistiklerle sınırlı olup, karar destek sistemi oldukça basittir. Bununla birlikte, düşük teknoloji uygulamaları dijital uçurumun azaltılması ve dijital okuryazarlığın geliştirilmesi açısından kritik bir başlangıç evresi oluşturmaktadır.

Düşük–Orta Teknoloji Uygulamaları

Düşük–orta teknoloji kategorisi, sensör sayısının ve çeşitliliğinin arttığı, veri toplamanın daha sistematik hâle geldiği ve konumsal bilginin üretim sürecine entegre edildiği çözümleri içermektedir. Bu grupta;

GPS tabanlı traktör yönlendirme sistemleri,

basit otomatik dümenleme,

daha gelişmiş toprak ve iklim sensör ağları,

temel uzaktan algılama verilerinin (uydu görüntüleri vb.) kullanıldığı karar destek panelleri ön plana çıkmaktadır (Sonka, 2020; FAO, 2019).

Literatürde bu teknolojilerin; yakıt tüketiminde düşüş, girdi kullanımında (özellikle gübre ve pestisit) tasarruf ve işgücü verimliliğinde artış gibi etkilerle farm düzeyinde kârlılığı iyileştirdiği gösterilmektedir (OECD, 2022; Abiri, 2023). Örneğin GPS destekli otomatik dümenleme sistemleri ile yakıt tüketiminin %5–10, girdi kullanımının ise %5–7 oranında azalabildiği rapor edilmektedir (FAO, 2022; Sonka, 2020). Bu düzeyde veri analizi hâlâ nispeten basit olmakla birlikte, mekânsal veri (haritalama) kullanımının artması, hassas tarımın temel bileşenlerinden biri olan değişken doz uygulamasına geçiş için altyapı hazırlamaktadır.

Orta–Yüksek Teknoloji Uygulamaları

Orta–yüksek teknoloji düzeyinde, hassas tarım uygulamaları belirginleşmekte; daha yoğun sensör kullanımı, uzaktan algılama, veri entegrasyonu ve gelişmiş analiz araçları devreye girmektedir. Bu kategoride;

çok bantlı (multispektral) sensörlerle donatılmış insansız hava araçları (dronlar),

verim monitörleri ve verim haritalama,

değişken oranlı (variable rate) gübre ve ilaç uygulama sistemleri,

Bulut tabanlı çiftlik yönetim yazılımları gibi çözümler yer almaktadır (Guebsi et al., 2024; Sonka, 2020).

Dronların bitki gelişimi, stres ve hastalık tespiti için kullanılmasına ilişkin çalışmalar, bu teknolojilerin hem tanı (diagnostik) hem de müdahale (ilaçlama, ekim vb.) aşamalarında önemli verimlilik kazançları sağladığını ortaya koymaktadır (Guebsi et al., 2024). Hassas tarım uygulamalarının, girdi kullanımını azaltırken verim ve kaliteyi artırarak hem ekonomik hem de çevresel fayda sağladığı; özellikle azot gübresi ve pestisit kullanımında %20–30'lara varan tasarruf potansiyeli taşıdığı vurgulanmaktadır (FAO, 2022; Abiri, 2023).

Bu düzeyde veri analizi; zaman serisi ve mekânsal analizler, zonlama, tahmin modelleri gibi daha ileri istatistiksel ve analitik yöntemleri içermekte, çiftçi kararlarını parcel altı düzeyde optimize etmeye imkân tanımaktadır. Orta–yüksek teknoloji uygulamaları, aynı zamanda tarla düzeyinde toplanan verilerin bölgesel ve ulusal karar destek sistemleriyle entegre edilmesine zemin hazırlamaktadır (FAO, 2023; World Bank, 2025).

Yüksek Teknoloji Uygulamaları

Yüksek teknoloji düzeyinde dijital tarım, yalnızca veri toplama ve izleme değil, tam entegre, yapay zekâ destekli, otonom ve blokzincir tabanlı sistemlerle bütüncül bir dönüşüm sürecine girmektedir. Bu kategori;

yapay zekâ ve makine öğrenmesi ile çalışan hastalık ve zararlı tahmin sistemlerini,

otonom traktörler, hasat makineleri ve tarla robotlarını,

gerçek zamanlı büyük veri analitiği yapan bulut platformlarını,

blokzincir temelli izlenebilirlik ve akıllı sözleşme uygulamalarını kapsamaktadır (FAO, 2023; FAO, 2024; Keramati et al., 2025).

FAO'nun yapay zekâ odaklı raporlarında; drone, akıllı telefon ve robotlar tarafından üretilen görüntülerin, yapay zekâ sistemleri ile işlenerek hastalık, besin noksanlığı ve su stresi tespitinde yüksek doğruluk sağladığı; böylece girdilerin tam zamanında ve hedefli kullanımına imkân verildiği vurgulanmaktadır (FAO, 2022; FAO, 2023). Diğer yandan, IBM Food Trust gibi blokzincir tabanlı sistemlerin tedarik zinciri izlenebilirliğini günler seviyesinden saniyeler seviyesine düşürdüğü; Walmart örneğinde mango tedarikinde iz sürme süresinin 7 günden 2,2 saniyeye gerilediği gösterilmiştir (Kamath, 2018; UNDP, 2021).

Yüksek teknoloji uygulamaları, yalnızca çiftlik içi verimliliği değil, aynı zamanda gıda güvenliği, geri çağırma süreçleri, ticaret ve tüketici güvenini de doğrudan etkilemektedir (Jouanjean, 2019; FAO, 2022). Bununla birlikte, bu düzeydeki teknolojilerin yüksek yatırım maliyetleri, veri yönetişimi, mahremiyet ve dijital eşitsizlik gibi yeni tartışmaları da gündeme getirdiği; bu nedenle kamu politikaları, standartlar ve kapsayıcı finansman modellerinin kritik olduğu vurgulanmaktadır (OECD, 2022; World Bank, 2019).

Sonuç olarak, düşük teknolojiden yüksek teknolojiye uzanan bu sınıflandırma, tarımda dijitalleşmenin basitten karmaşığa doğru evrilen bir süreç olduğunu göstermektedir. Her bir düzey, bir sonrakine geçiş için ön koşul niteliği taşımakta; bu nedenle ülkelerin dijital tarım stratejilerini kademeli, kapsayıcı ve çiftçi odaklı bir yol haritası üzerine inşa etmeleri gerekmektedir.

Dijital Tarım Teknolojilerinin Tarımsal Üretime Etkileri

Dijital tarım teknolojileri farklı düzeylerde ve farklı ürün/hayvancılık sistemlerinde uygulansa da, literatürde ortaya çıkan temel etkiler benzer başlıklar altında toplanmaktadır. Aşağıda bu etkilere ilişkin bazı özetler Tablo 1' de verilmiştir;

Tablo 1. Dijital Tarım Teknolojileri ve Uygulama Etkilerine İlişkin Bazı Çalışma Özetleri

Yazarlar ve Yıl	Teknoloji / Uygulama	Alan / Ürün	Temel Verimlilik Bulgu ve Artış Oranları
Schimmelpfennig (2018)	Hassas Tarım (PA) / Değişken Oranlı Gübreleme	ABD Mısır ve Soya	PA'nın benimsenmesi, ortalama olarak **%4 ile %6 arasında verim artışı** sağlarken, gübre ve ilaç kullanımını azalttığı tespit edilmiştir.
Pallottino vd. (2018)	IoT ve Sensör Tabanlı Sulama	İtalya Bağcılık	Akıllı sensörler aracılığıyla gerçekleştirilen değişken oranlı sulama, **su kullanımında %15-20 tasarruf** sağlarken, ürün kalitesini korumuştur. Bu, birim su başına verimlilikte önemli bir artış anlamına gelir.
Lowenberg-DeBoer & Erickson (2019)	Otomasyon (Robotik) ve Yapay Görme	Genel Tarım	Robotik ve yapay görme sistemlerinin, özellikle yabani otla mücadelede (ototlu ilaçlama) **ilaç kullanımını %70'e kadar düşürdüğü** ve bu sayede girdi maliyetini azaltarak net karlılığı artırdığı vurgulanmıştır.
Krueger vd. (2020)	Uzaktan Algılama (Drone/Uydu) ve Analiz	Almanya Tahıl Üretimi	Erken hastalık ve besin eksikliği tespiti sayesinde zamanında müdahale olanağı sağlamış, bu da mahsul kaybını minimuma indirerek **verimlilik artışına dolaylı katkı** yapmıştır.
Gebbers & Adamchuk (2010)	Toprak Haritalama ve PA	Çeşitli Ürünler	Hassas toprak yönetimi ve parseller arası farklılıkların haritalanması, gübrenin sadece ihtiyaç duyulan yere uygulanmasını sağlamıştır. Bu, **toprak verimliliğini korurken, gübre kullanımında %10-20 arasında optimizasyon** sağlamıştır.

Verimlilik Artışı

Dijital teknolojiler, arazi içi heterojenliği yüksek çözünürlükte ortaya koyarak hedefe yönelik müdahale imkânı sağlar. Hassas gübreleme, değişken oranlı ilaçlama ve satıhtan sensör destekli ekim kararları sayesinde aynı alanda daha yüksek biyolojik ve ekonomik verim elde edilir (Abiri ve ark., 2023; Getahun ve ark., 2024). Lowenberg-DeBoer & Erickson (2019), hassas ekim ve değişken oranlı ilaçlama uygulamalarının, kaynakların en verimli şekilde kullanılmasını sağlayarak tarladaki verim farklılıklarını (heterojenliği) azalttığını belirtir. Bu sayede, tarla içindeki düşük performanslı alanlar belirlenir ve düzeltilir, bu da genel verimi yukarı çekmektedir.

Akıllı sulama sistemleri ve sera otomasyonunda ise, sensör verisine dayalı iklim kontrolü, bitki gelişiminde stabilite sağlayarak verim dalgalanmalarını azaltmaktadır (Shamshiri ve ark., 2024). Meta-analiz bulguları, hassas tarım uygulamalarının verimde %5–20 arası artış sağlayabildiğini, özellikle yüksek girdi kullanılan sistemlerde bu etkinin daha belirgin olduğunu ortaya koymaktadır (Finger ve ark., 2023; Papadopoulos ve ark., 2024).

Su ve Enerji Tasarrufu

Su kıtlığının arttığı koşullarda dijital sulama sistemleri kritik önem taşımaktadır. IoT tabanlı sensörler ve YZ destekli sulama kararları, suyun yalnızca ihtiyaç duyulan zaman ve dozda uygulanmasını mümkün kılmaktadır. Türkiye ve dünya genelindeki pilot projeler, bu sistemler sayesinde sulama suyunda %20–40, bazı çalışmalarda %50'nin üzerinde tasarruf sağlandığını göstermektedir (Abiri ve ark., 2023; Ahmed ve ark., 2025). Pallottino vd. (2018) gibi araştırmacılar, akıllı sulama sistemlerinin suyu sadece doğru zamanda değil, doğru miktarda ve doğru alana vermesi sayesinde sulanan alanlarda %20'ye varan su tasarrufunun yaygın bir bulgu olduğunu göstermiştir. Bu, su kıtlığı çeken bölgelerde sürdürülebilir bir verimlilik artışının anahtarıdır.

İHA ve uydu görüntülerine dayalı bitki su stresi haritaları, sulama planlarını daha isabetli hâle getirerek hem su hem de enerji tüketimini azaltmaktadır. Özellikle pompajla sulama yapılan alanlarda, enerji tasarrufu çiftçi gelirine doğrudan olumlu yansımaktadır (Raj, 2025).

Girdi Maliyetlerinin Azalması

Dijital tarımın en somut çıktılarından biri de girdi maliyetlerinin düşmesidir. Değişken oranlı gübreleme, sadece ihtiyaç duyulan alanlara ve dozlara uygulama yapılmasını sağlayarak gübre tüketimini azaltır; benzer biçimde, sensör ve görüntü analizine dayalı hassas ilaçlama da pestisit kullanımını önemli ölçüde düşürür (Anastasiou ve ark., 2023; Kumar ve ark., 2024).

Raj'ın (2025) derlemesine göre, dijital teknolojilerin bütünleşik kullanıldığı örneklerde gübre tüketiminde %10–30, pestisit tüketiminde %15–25, yakıt kullanımında ise %10'a varan azalmalar rapor edilmektedir. Bu tasarruf, özellikle artan girdi fiyatları karşısında çiftçi kârlılığını korumada kritik bir araç hâline gelmiştir.

Ürün Kalitesi ve Standart Artışı

Sensörler, İHA'lar ve görüntü işleme algoritmaları sayesinde bitki gelişimi, besin elementi eksiklikleri ve hastalık–zararlı sorunları daha erken safhada tespit edilebilmektedir. Bu sayede reaksiyon süresi kısalmakta, kaliteyi bozan stres faktörleri azaltılmaktadır (Ramsari ve ark., 2024; Agrawal ve ark., 2024).

Seralarda sıcaklık, nem, CO_2 ve ışık şiddetinin otomasyonla sınır değerler içinde tutulması, özellikle sebze ve meyve üretiminde daha homojen ürün kalitesi, raf ömründe artış ve ihracat standartlarına uyumu kolaylaştırmaktadır (Shamshiri ve ark., 2024; EPO, 2024).

Hasat–Depolama Kayıplarının Azalması

Dijital tarım yalnızca tarladaki üretim sürecine değil, hasat, depolama ve lojistik aşamalarına da etki etmektedir. Sensör tabanlı olgunluk izleme, hasat zamanının daha isabetli belirlenmesini sağlayarak tarladaki kayıpları azaltırken, soğuk zincir izleme sistemleri ve akıllı depolama çözümleri depo içi sıcaklık, nem, gaz konsantrasyonu gibi parametreleri sürekli izleyerek bozulma riskini azaltmaktadır (Benyam ve ark., 2021).

Gıda kayıp ve israfını inceleyen çalışmalar, dijital teknolojilerin üretim–depolama–dağıtım zinciri boyunca kayıpları %10–30 aralığında azaltma potansiyeline sahip olduğunu ortaya koymaktadır (Taner, 2024).

Gıda Güvenliği ve İzlenebilirlik (Blockchain)

Blokzincir tabanlı izlenebilirlik sistemleri, tarımsal ürünlerin tarladan sofraya tüm yolculuğunu şeffaf ve değiştirilemez bir biçimde kayıt altına almayı mümkün kılmaktadır. Üretim tarihi, kullanılan girdiler, depolama koşulları ve lojistik bilgiler blokzincire işlendiğinde, hem kamu otoritesi hem de tüketici için güçlü bir doğrulama mekanizması oluşmaktadır (Ellahi ve ark., 2024).

Son yıllardaki incelemeler, blokzincir tabanlı gıda tedarik zinciri projelerinin geri çağırma sürelerini kısalttığını, sahtecilik ve tağşiş riskini azalttığını ve tüketici güvenini artırdığını göstermektedir (Sri Vigna Hema ve ark., 2024). Bu sistemler, özellikle süt ürünleri, et ve taze sebze–meyve gibi gıda güvenliği açısından kritik ürünlerde önem kazanmaktadır.

İşgücü ve Zaman Tasarrufu

Otonom traktörler ve ilaçlama drone'ları, insan emeği gerektiren işlerin hızını ve hassasiyetini artırarak işgücü maliyetlerini azaltır ve çiftçinin zamanını daha stratejik kararlara ayırmasını sağlar. Bu, birim zaman başına üretilen mahsul miktarını (emek verimliliği) artırır. Dijital teknolojiler, hem manuel iş yükünü azaltmakta hem de iş organizasyonunu rasyonelleştirmektedir. GPS'li ve otomatik dümenlemeli traktörler, operatör yorgunluğunu azaltırken aynı alanın daha kısa sürede işlenmesini sağlar; İHA'lar sayesinde büyük alanların gözlemi dakikalar içinde tamamlanabilmektedir (Rejeb ve ark., 2022; Raj, 2025).

OECD raporları, dijital teknolojileri daha yoğun kullanan işletmelerde işgücü verimliliğinin anlamlı biçimde yükseldiğini; bazı faaliyetlerde işgücü ihtiyacının %15–20 azaldığını göstermektedir (OECD, 2024; McFadden ve ark., 2022). Bu durum, özellikle kırsalda genç nüfusun azaldığı ve yaşlı çiftçi oranının arttığı ülkeler için stratejik önem taşımaktadır.

Çiftçi Gelirinde Artış

Verim artışı, girdi ve işgücü tasarrufu ile kalite ve pazarlama avantajları birlikte değerlendirildiğinde, dijital tarım teknolojilerinin çiftçi geliri üzerinde net pozitif etki yarattığı görülmektedir. Abiri ve ark. (2023), farklı ülkelerden vaka çalışmalarını derledikleri çalışmalarında, dijital teknolojilerin bazı örneklerde çiftçi net gelirini %10–25 oranında artırabildiğini rapor etmektedir. Schimmelpfennig (2018), ABD'deki mısır ve soya çiftlikleri üzerinde yaptığı çalışmada, PA'nın benimsenmesinin ekonomik analizini yapmış ve girdilerdeki tasarrufun ve küçük verim artışlarının birleşimiyle çiftçilerin net karlılıklarında anlamlı bir artış olduğunu kanıtlamıştır.

Benzer biçimde Finger ve ark. (2023), dijital inovasyonların hem volatilitiyi düşürerek gelir istikrarını artırdığını hem de risk yönetimini güçlendirdiğini vurgulamaktadır. Ancak bu kazanımların tüm çiftçi grupları için eşit olmadığının; sermaye, eğitim düzeyi ve dijital altyapı açısından dezavantajlı gruplar için hedefli destek politikalarına ihtiyaç bulunduğunun da altı çizilmektedir (OECD, 2024; McFadden ve ark., 2022).

Çevresel Fayda ve Sürdürülebilirlik

Dijital tarımın en kritik çıktılarından biri de çevresel baskıların azaltılmasıdır. Girdi kullanımındaki azalma, toprak–su–hava kirliliğini sınırlandırmakta; sera gazı emisyonlarını düşürmektedir. IoT, YZ ve büyük veri destekli sistemler, özellikle su–enerji–gıda ilişkisini dikkate alan sürdürülebilir yönetim modelleri geliştirilmesine katkı sağlamaktadır (Dayıoğlu, 2021; Shamshiri ve ark., 2024).

Çeşitli derlemeler, dijital inovasyonların doğru uygulandığında su kullanımını, nitrat sızıntısını ve pestisit yayılımını azaltırken, aynı zamanda iklim değişikliğine uyum kapasitesini artırabildiğini ortaya koymaktadır (Finger ve ark., 2023; Papadopoulos ve ark., 2024; Ahmed ve ark., 2025). Böylece dijital tarım, yalnızca ekonomik değil, aynı zamanda ekolojik ve toplumsal sürdürülebilirliğin de temel araçlarından biri hâline gelmektedir.

Türkiye'de Dijital Tarımın Geliştirilmesi İçin Politika ve Strateji Önerileri

Türkiye'de dijital tarımın ölçek kazanabilmesi için ilk ve temel adım, güçlü bir dijital tarım altyapısının oluşturulmasıdır. Kırsal alanda genişbant internet erişiminin yetersizliği, sensör, uydu ve makine verilerinin aktarımını sınırlamakta; bulut tabanlı karar destek sistemlerinin kullanımını da zorlaştırmaktadır. FAO'nun dijital tarım ve yapay zekâ yol haritası, ülkelerin öncelikle güvenli veri altyapısı, ulusal tarımsal veri standartları ve çiftçi haklarını gözeten veri yönetişimi çerçeveleri oluşturmaları gerektiğini vurgulamaktadır (FAO, 2025). Dünya Bankası'nın dijital tarım profilleri de Türkiye dâhil pek çok ülkede dijital altyapının gelişmiş olmasına rağmen, küçük ölçekli işletmelerde bağlantı, donanım maliyeti ve dijital okuryazarlık eksikliği nedeniyle teknolojilerin yeterince kullanılamadığını göstermektedir (World Bank, 2021). Bu nedenle Türkiye'de kırsal genişbant yatırımları, tarımsal veri merkezleri, ulusal tarım veri tabanı ve DİTAP benzeri platformların güçlendirilmesi; sensör, IoT ve makine verilerinin ortak bir standartta toplanarak kamu, üniversite ve özel sektörün kullanımına açılması temel bir politika alanı olmalıdır. Böyle bir altyapı, hem kamunun tarımsal destekleri daha hedefli tasarlamasına hem de firmaların çiftçilere veri temelli dijital hizmetler geliştirmesine imkân verecektir (OECD, 2019).

Türkiye gibi su stresi yüksek ülkelerde dijital tarım politikalarının merkezine akıllı sulama ve su yönetimi yerleştirilmelidir. Su çekiminin büyük kısmının tarımsal sulamadan kaynaklandığı koşullarda, damla sulama, sensör destekli nem takibi, otomatik sulama sistemleri ve uzaktan izleme teknolojileri su verimliliğini artırmak için kritik önemdedir. FAO ve Dünya Bankası'nın iklim akıllı tarım çalışmalarında, dijital sulama çözümlerinin bir yandan verimi korurken diğer yandan su tüketimini ciddi biçimde azaltabildiği, bunun da kuraklık riskine uyum kapasitesini yükselttiği gösterilmektedir (World Bank, 2024; FAO, 2023). Türkiye'de tarımsal sulamada su sayaçlarının dijitalleştirilmesi, su kotası ve fiyatlandırma politikalarının sensör verileriyle entegre edilmesi, baraj ve yeraltı suyu izleme sistemlerinin gerçek zamanlı veriyle yönetilmesi, havza bazlı su tahsis planlarının dijital karar destek sistemleri üzerinden yapılması, hem çevresel sürdürülebilirliği güçlendirecek hem de üreticilere suyu en verimli kullanan işletme olma yönünde ekonomik motivasyon sağlayacaktır.

Drone ve uydu destekli izleme sistemleri, Türkiye'de hem tarımsal verimliliğin artırılmasında hem de tarımsal desteklerin denetlenmesinde önemli bir politika aracı hâline gelebilir. Avrupa Birliği ve OECD ülkelerinde, uydu görüntüleriyle ürün gelişimini ve arazi kullanımını izleyen sistemlerin, destek suiistimallerini azalttığı, çevresel şartlılıkların (çevreye duyarlı destek) denetimini kolaylaştırdığı ve afet-sonrası zarar tespitini hızlandırdığı rapor edilmektedir (OECD, 2023). Türkiye'de de ÇKS verisinin uydu ve drone görüntüleriyle entegrasyonu, ekim deseninin ve nadas alanlarının izlenmesi, ürün hastalık ve zararlı yoğunluğu haritalarının oluşturulması ve bu haritaların sigorta, kredi ve destek politikalarına entegre edilmesi, tarımsal politikalarda isabet oranını artıracaktır. Aynı zamanda, bu görüntülerin üretici örgütleri ve kooperatiflerle paylaşılması; girdi kullanımının optimizasyonu, hasat zamanının planlanması ve pazarlama stratejilerinin geliştirilmesi açısından da önemli fırsatlar sunmaktadır (FAO, 2024).

Dijital tarımın kritik bileşenlerinden biri de büyük veri ve yapay zekâ uygulamalarıdır. FAO'nun stratejik çerçevesinde, tarımsal üretimden pazarlamaya kadar oluşan çok büyük hacimli verinin makine öğrenmesi ve yapay zekâ ile analiz edilmesinin, hem verimliliği hem de çevresel performansı iyileştirmek için büyük potansiyel taşıdığı vurgulanmaktadır (FAO, 2022). Türkiye'de iklim verileri, toprak analiz sonuçları, uydu görüntüleri, fiyat serileri, girdi kullanım kayıtları ve çiftçi davranış verilerinin bütünleşik bir yapıda toplanması ve anonimleştirilerek araştırma kurumları ile özel sektöre açılması, veriye dayalı modellerin geliştirilmesini mümkün kılacaktır. Bu modeller; ürün deseni planlaması, verim tahmini, hastalık ve zararlı erken uyarıları, fiyat dalgalanmalarının öngörülmesi ve karbon ayak izi hesaplamaları gibi alanlarda kullanılabilir. OECD raporları, dijital teknolojilerin doğru tasarlanmış politikalarla birleştiğinde tarımsal üretimde verim artışı sağlarken, girdi kullanımını optimize ederek çevresel baskıları da azaltabildiğini göstermektedir (OECD, 2019). Bu çerçevede Türkiye'de "ulusal tarımsal büyük veri ve yapay zekâ merkezi" benzeri bir oluşumun desteklenmesi, üniversite–sanayi–kamu işbirliğiyle algoritmaların tarla ölçeğinde test edilmesi stratejik öncelik olmalıdır.

Sensör tabanlı hayvancılık sistemleri, Türkiye'nin önemli bir potansiyel barındırdığı bir başka dijitalleşme alanıdır. Ruminant işletmelerde sürü sağlığının, yem tüketiminin, hareketliliğin, vücut sıcaklığının ve süt veriminin sensörlerle izlenmesi; hastalıkların erken teşhis edilmesi, antibiyotik ve ilaç kullanımının azaltılması, yem verimliliğinin ve hayvan refahının yükseltilmesi açısından önemli kazanımlar sağlamaktadır. FAO ve Dünya Bankası, sensör tabanlı hayvancılık teknolojilerinin, birim hayvan başına verimi artırarak hem üretici gelirlerini yükseltebileceğini hem de sera gazı emisyonlarını azaltabileceğini belirtmektedir (FAO, 2022; World Bank, 2024). Türkiye'de kırmızı ve beyaz et, süt ve yumurta üretiminde rekabetçiliğin korunması için, özellikle orta ve büyük ölçekli işletmelerde sensör tabanlı yönetim sistemlerinin destek kapsamına alınması, yatırım ve işletme kredilerinde pozitif ayrımcılık yapılması ve bu teknolojilerin kooperatifler aracılığıyla küçük ölçekli üreticilere uygun maliyetle ulaştırılması önemlidir. Ayrıca, sensör verilerinin sigorta ve kredi değerlendirmelerinde risk analizine dâhil edilmesi, finans sektörünün de dijital hayvancılık yatırımlarına daha istekli yaklaşmasını sağlayacaktır.

Gıda güvenliği ve izlenebilirlik boyutunda blockchain tabanlı çözümler, Türkiye için hem iç pazar hem de ihracat pazarları açısından stratejik imkânlar sunmaktadır. Blockchain tabanlı izlenebilirlik sistemlerinin, gıda tedarik zincirinde veri bütünlüğünü ve şeffaflığı artırarak, geri çağırma maliyetlerini düşürdüğü ve tüketici güvenini güçlendirdiği; çok sayıda uluslararası çalışma tarafından ortaya konmuştur (Mirabelli & Solina, 2020; van Hilten et al., 2020). UNDP'nin gıda izlenebilirliğine yönelik raporunda da bu teknolojinin Küresel Amaçlar başta olmak üzere gıda güvenliği, adil ticaret ve küçük çiftçi lehine gelir dağılımı gibi alanlarda önemli katkı sağlayabileceği vurgulanmaktadır (UNDP, 2021). Türkiye'de özellikle ihracat odaklı yaş meyve–sebze, zeytin–zeytinyağı, fındık, üzüm ve organik ürün zincirlerinde blockchain tabanlı izlenebilirlik projelerinin desteklenmesi; kooperatif ve üretici birliklerinin bu sistemlere entegre edilmesi ve tüketicilere QR kodları üzerinden ürün hikâyesinin sunulması, Türk tarım ürünlerinin markalaşmasına ve fiyatlama gücünün artmasına katkı sağlayacaktır.

Dijitalleşme politikalarının bir diğer ayağı da mekanizasyon ve otonom tarım araçlarıdır. Otomatik dümenleme sistemleri, sensör destekli ekipmanlar, otonom traktörler ve robotik hasat makineleri; özellikle işgücü kıtlığı yaşayan bölgelerde üretim maliyetlerini düşürmekte ve iş süreçlerini hızlandırmaktadır. FAO'nun tarımsal otomasyonla ilgili politika notlarına göre, uygun şekilde tasarlanan otomasyon yatırımları; verimliliği artırmakla kalmamakta, aynı zamanda iş sağlığı ve güvenliği risklerini azaltmakta ve genç nüfusu tarıma yeniden çekebilmektedir (FAO, 2022). Türkiye'de yaşlanan kırsal nüfus ve mevsimlik işgücü arzındaki dalgalanmalar dikkate alındığında, otonom tarım ekipmanlarının yatırımlarında KDV ve gümrük muafiyetleri, uygun faizli krediler ve leasing modelleriyle desteklenmesi, aynı zamanda yerli makine sanayinin dijital donanım üretimine yönlendirilmesi önem taşımaktadır.

Akıllı depolama ve lojistik sistemleri de dijital tarım stratejisinin ayrılmaz parçasıdır. FAO ve OECD, hasat sonrası kayıpların özellikle gelişmekte olan ülkelerde toplam üretimin ciddi bir kısmını oluşturduğunu ve dijital soğuk zincir, akıllı silo ve stok yönetim sistemlerinin bu kayıpları önemli ölçüde azaltabileceğini vurgulamaktadır (FAO, 2023; OECD, 2019). Türkiye'de lisanslı depoculuk sisteminin dijitalleştirilmesi, ürün senetlerinin blockchain veya benzeri güvenli kayıt sistemlerinde tutulması, depo sıcaklık ve nem değerlerinin sensörlerle izlenerek yapay zekâ ile optimize edilmesi, hem üretici gelirini artıracak hem de fiyat dalgalanmalarını azaltacaktır. Lojistik tarafında ise, ürün hareketlerinin gerçek zamanlı izlenmesi, rota optimizasyonu ve karbon ayak izi hesaplamaları; tarım ürünlerinin iç ve dış pazarlardaki rekabet gücünü güçlendirecektir.

Tüm bu teknolojik dönüşümün başarısı, eğitim, yayım ve dijital okuryazarlık programlarıyla doğrudan ilişkilidir. FAO ve Digital Agri Hub'ın Avrupa ve Orta Asya için hazırladığı raporlarda, dijital tarım projelerinin başarısının büyük ölçüde çiftçilerin dijital okuryazarlık düzeyine, güven ilişkilerine ve yerel kurumların kapasitesine bağlı olduğu belirtilmektedir (FAO, 2024). Türkiye'de tarım meslek liseleri, ziraat fakülteleri, tarım danışmanları ve çiftçi örgütleri üzerinden dijital tarım eğitim modülleri geliştirilmesi; kadın ve genç çiftçilere yönelik özel dijital okuryazarlık programları tasarlanması ve bu programların sahada uygulamalı olarak yürütülmesi gerekmektedir. Dijital tarım platformlarının Türkçe ve sade arayüzlerle tasarlanması, sesli ve görsel eğitim içerikleriyle desteklenmesi ve çiftçinin karar süreçlerine güvenilir bir "dijital danışman" olarak entegre edilmesi de politika yapıcıların dikkat etmesi gereken noktalardır.

Son olarak, dijital tarım ekosisteminin sürdürülebilir biçimde gelişebilmesi için güçlü kamu–üniversite–özel sektör işbirliği modellerine ihtiyaç vardır. OECD ve Dünya Bankası raporları, dijital tarımda başarılı örneklerin çoğunda, kamu kurumlarının düzenleyici ve kolaylaştırıcı, özel sektörün yenilikçi ve yatırımcı, üniversitelerin ise bilgi üretici ve nitelikli insan kaynağı yetiştirici rolü üstlendiğini göstermektedir (OECD, 2019; World Bank, 2024). Türkiye'de Tarım ve Orman Bakanlığı, Sanayi ve Teknoloji Bakanlığı, TÜBİTAK, üniversiteler, teknoparklar, start-up'lar ve kooperatifler arasında "Dijital Tarım İnovasyon Merkezleri" kurulması; bu merkezlerde Ar-Ge projeleri, pilot uygulamalar ve ölçekleme programlarının yürütülmesi, dijital tarım girişimlerinin fonlara erişiminin kolaylaştırılması ve kamu alımları yoluyla yerli dijital tarım çözümlerinin teşvik edilmesi önemlidir. Böylece dijital tarım, sadece teknoloji ithal edilen bir alan olmaktan çıkarak, Türkiye'nin bölgesel ölçekte rekabet avantajı elde ettiği bir uzmanlık alanına dönüşebilir.

Sonuç ve Değerlendirme

Dijital tarım, günümüz tarımsal üretim sistemlerinde artık bir tercih değil, giderek artan küresel riskler karşısında zorunlu bir dönüşüm alanı olarak ortaya çıkmaktadır. İklim değişikliğinin yol açtığı sıcaklık artışları, su kıtlığı, ekstrem hava olaylarının sıklığındaki yükseliş ve buna bağlı verim kayıpları, geleneksel üretim teknikleriyle sürdürülebilir bir tarımsal yapının korunamayacağını açıkça göstermektedir. Bu nedenle tarımsal verimliliği artıran, su ve girdi kullanımını optimize eden, üretim planlamasını bilimsel ve veri temelli bir zemine oturtan dijital teknolojiler, hem küresel hem de ulusal ölçekte gıda güvenliğinin geleceğini belirleyen stratejik araçlar hâline gelmiştir. Türkiye'nin içinde bulunduğu iklimsel, ekonomik ve sosyal baskılar değerlendirildiğinde dijitalleşmenin, tarımsal üretim sistemlerinin dayanıklılığını artırmak için en rasyonel politika seçeneği olduğu görülmektedir.

Türkiye açısından dijital tarım, hem mevcut sorunlara çözüm üretme hem de yeni fırsat alanları yaratma potansiyeline sahiptir. Su stresi altında bulunan tarım havzalarında akıllı sulama sistemleri, sensör tabanlı izleme teknolojileri ve yerli-yabancı uydu verileriyle koordineli çalışan karar destek mekanizmaları, üretimde hem verim kaybını azaltmakta hem de kaynak kullanım etkinliğini artırmaktadır. Bunun yanında, blockchain tabanlı izlenebilirlik sistemleri Türkiye'nin tarım ve gıda ihracatında kalite güvencesini üst seviyeye taşıyacak, özellikle Avrupa Birliği pazarında rekabet üstünlüğü sağlayacaktır. Drone tabanlı hastalık ve zararlı tespiti, yapay zekâ destekli üretim tahminleri, otonom tarım makineleri ve akıllı lojistik çözümleri ise hem üretim maliyetlerini düşürmekte hem de tarımsal işgücünde yaşanan yaşlanma ve istihdam azalması sorunlarının etkilerini hafifletmektedir. Bu çerçevede dijitalleşme, yalnızca üretim sürecinin teknik bir iyileştirmesi değil, aynı zamanda Türkiye'nin gıda sisteminde verimlilik, sürdürülebilirlik, kalite ve küresel rekabet gücünü doğrudan belirleyen bir kalkınma stratejisidir.

Politika yapıcılar, özel sektör ve akademi için ortaya çıkan temel stratejik öneriler ise çok boyutludur. Öncelikle ulusal bir tarımsal dijitalleşme stratejisinin hazırlanması ve tüm paydaşların ortak veri altyapısında buluşturulması gerekmektedir. Dijital tarım ekosisteminin gelişebilmesi için güçlü bir Ar-Ge ve inovasyon ortamı oluşturulmalı, üniversiteler ile teknoloji firmaları arasındaki işbirlikleri teşvik edilmeli, start-up ekosistemi desteklenmelidir. Çiftçilerin dijital okuryazarlığını geliştirmeye yönelik eğitim programları yaygınlaştırılmalı; kadın ve genç çiftçiler dijital dönüşüm sürecinin öncü grubu hâline getirilmelidir. Kamu–üniversite–özel sektör arasında bütüncül bir işbirliği modeli kurularak karar destek sistemleri, sensör teknolojileri, yapay zekâ temelli uygulamalar ve izlenebilirlik teknolojileri alanlarında yerli çözümlerin geliştirilmesi sağlanmalıdır. Bu adımların hayata geçirilmesi, Türkiye'nin tarımsal üretim sistemlerini iklim risklerine karşı daha dayanıklı, ekonomik olarak daha rekabetçi ve çevresel açıdan daha sürdürülebilir bir yapıya kavuşturacaktır.

Kaynakça

Abiri, R., Rizan, N., Balasundram, S. K., Shahbazi, A. B., & Abdul-Hamid, H. (2023). Application of digital technologies for ensuring agricultural productivity. *Heliyon, 9*(12), e22601. https://doi.org/10.1016/j.heliyon.2023.e22601

Ahmed, N., Wan, S., Zhang, F., & Zhong, W. (2025). Advancing agriculture through IoT, Big Data, and AI. *Journal of Agriculture and Food Research, 14*, 100–118.

Alsanhani, A. N., Alotaibi, B. M., & Alshamrani, S. (2025). The role of the "Agricultural Guide" app in improving olive farming sustainability in Saudi Arabia. *Sustainability, 17*(6), 2340. https://doi.org/10.3390/su17062340

Anastasiou, E., Fountas, S., Voulgaraki, M., Psiroukis, V., & Koutsiaras, M. (2023). Precision farming technologies for crop protection: A meta-analysis. *Smart Agricultural Technology, 5*, 100323.

Benyam, A. A., Feng, L., & Zhang, X. (2021). Digital agricultural technologies for food loss and waste prevention and reduction: A review. *Journal of Cleaner Production, 323*, 129099.

Consilium (2024). Digital Agriculture Market Overview. Council of the European Union. https://www.consilium.europa.eu/media/31jkkbxi/2024_971-art-agriculture-02.pdf

Dayıoğlu, M. A. (2021). Digital transformation for sustainable future: Agriculture 4.0 and water-energy-food nexus. *Ankara Üniversitesi Tarım Bilimleri Dergisi, 27*(4), 776–792.

Ellahi, R. M., Wood, L. C., & Bekhit, A. E.-D. A. (2024). Blockchain-driven food supply chains: A systematic review for unexplored opportunities. *Applied Sciences, 14*(19), 8944. https://doi.org/10.3390/app14198944

European Patent Office. (2024). *Digital agriculture – Towards sustainable food security*. EPO Technology Insight Report.

FAO. (2022). *The State of Food and Agriculture 2022: Leveraging automation in agriculture for transforming agrifood systems*. Food and Agriculture Organization of the United Nations.

FAO. (2023). *Digital agriculture: Towards sustainable food security*. Food and Agriculture Organization of the United Nations.

FAO. (2024). *Digital agriculture and AI innovation*. FAO Innovation Office.

FAO. (2024). *Digital agriculture in Europe and Central Asia*. FAO Regional Office for Europe and Central Asia.

FAO. (2025). *Digital agriculture and AI innovation*. Food and Agriculture Organization of the United Nations.

FAO. (2025). *Global food security and agriculture outlook 2025*. Food and Agriculture Organization of the United Nations.

FAO. (2025). *State of Food Security and Nutrition in the World 2025*. Food and Agriculture Organization.

Finger, R., Swinton, S. M., El Benni, N., & Walter, A. (2023). Digital innovations for sustainable and resilient agricultural systems. *European Review of Agricultural Economics, 50*(4), 1277–1309.

Food and Agriculture Organization. (2019). *Digital technologies in agriculture and rural areas: Status report*. FAO.

Food and Agriculture Organization. (2022). *The State of Food and Agriculture 2022: Leveraging automation in agriculture for transforming agrifood systems*. FAO.

Food and Agriculture Organization. (2023). *Digital agriculture for better production – FAO Programme Priority Area*. FAO.

Gebbers, R., & Adamchuk, V. I. (2010). Precision agriculture and food security. Science, 328(5977), 444-448. (DOI: 10.1126/science.1183899)

Getahun, S., Xie, H., & Li, Y. (2024). Application of precision agriculture technologies for sustainable crop production: A review. *Smart Agricultural Technology, 8*, 100441.

Global Market Insights (2024). Digital Agriculture Market Report 2024–2032. https://www.gminsights.com/industry-analysis/digital-agriculture-market

Guebsi, R., et al. (2024). Drones in precision agriculture: A comprehensive review of technological advances and applications. *Drones, 8*(11), 686.

IPCC. (2023). *Climate Change 2023: Synthesis Report*. Intergovernmental Panel on Climate Change.

IPCC. (2024). *Climate Change Assessment Report*. Intergovernmental Panel on Climate Change.

Jouanjean, M.-A. (2019). *Digital opportunities for trade in the agriculture and food sectors*. OECD Publishing.

Kamath, R. (2018). Food traceability on blockchain: Walmart's pork and mango pilots with IBM. *The Journal of the British Blockchain Association, 1*(1).

Keramati, A., et al. (2025). Blockchain's effects on responsiveness to recalls in the food supply chain. *Food Control*.

Krueger, L. L., Pütz, N., & Beulshausen, S. (2020). Precision agriculture technologies and their impact on farm profitability: A systematic review. Precision Agriculture, 21(5), 1017–1041. (DOI: 10.1007/s11119-020-09722-1)

Lowenberg-DeBoer, J., & Erickson, B. (2019). The economics of precision agriculture and its impact on the sustainability of production systems. Sustainability, 11(13), 37-46. (DOI: 10.3390/su11133746)

Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, 50(4), 370–396.

McFadden, J., Casalini, F., & Antón, J. (2022). *The digitalisation of agriculture: A literature review and emerging policy issues* (OECD Food, Agriculture and Fisheries Paper No. 176). OECD Publishing.

Mirabelli, G., & Solina, V. (2020). Blockchain and agricultural supply chains traceability: Research trends and future challenges. *Procedia Manufacturing, 42*, 414–421.

OECD (2022). The Digitalisation of Agriculture. OECD Publishing. https://www.oecd.org/content/dam/oecd/en/publications/reports/2022/04/the-digitalisation-of-agriculture_dd2a1973/285cc27d-en.pdf

OECD. (2019). *Digital opportunities for better agricultural policies*. OECD Publishing.

OECD. (2023). *The digital transformation of the agriculture and food system*. OECD Publishing.

OECD. (2024). *The digitalisation of agriculture*. OECD Publishing.

Organisation for Economic Co-operation and Development. (2022). *The digitalisation of agriculture*. OECD Publishing.

Pallottino, F., Biocca, M., Vieri, M., & Manetto, G. (2018). Irrigation management with IoT technologies for smart farming applications. Journal of Agricultural Engineering, 49(2), 53-60. (DOI: 10.4081/jae.2018.828)

Papadopoulos, G., Arduini, S., Uyar, H., Psiroukis, V., Kasimati, A., & Fountas, S. (2024). Economic and environmental benefits of digital agricultural technologies in crop production: A review. *Smart Agricultural Technology, 8*, 100441.

Raj, M. (2025). Revolutionizing agriculture: A review of smart farming technologies for a sustainable future. *SN Applied Sciences, 7*, 561.

Ramsari, N., Suhardi, S., Faizal, A., & Andrianto, H. (2024). Technologies for detecting nutrient deficiencies in plants: A review of AI and IoT-based approaches. In *Proceedings of the 2024 International Conference on Information Technology Systems and Innovation* (pp. 1–6). IEEE.

Rejeb, A., Abdollahi, A., Rejeb, K., & Treiblmaier, H. (2022). Drones in agriculture: A review and bibliometric analysis. *Computers and Electronics in Agriculture, 198*, 107017.

Schimmelpfennig, D. E. (2018). Farm Profits and Adoption of Precision Agriculture. Economic Research Report No. 249, USDA Economic Research Service.

Shamshiri, R. R., Sturm, B., Weltzien, C., Fulton, J., Khosla, R., Schirrmann, M., Raut, S., Basavegowda, D. H., Yamin, M., & Hameed, I. A. (2024). Digitalization of agriculture for sustainable crop production: A use-case review. *Frontiers in Environmental Science, 12*, 1375193. https://doi.org/10.3389/fenvs.2024.1375193

Sonka, S. T. (2020). Digital technologies, big data, and agricultural innovation. In *The Innovation Revolution in Agriculture* (pp. 135–154). Springer.

Sri Vigna Hema, V., Dhinesh Kumar, R., & Baskar, G. (2024). Blockchain for food safety in supply chain: A review. *Comprehensive Reviews in Food Science and Food Safety, 23*(2), 1–30.

Trendov, N. M., Varas, S., & Zeng, M. (2019). *Digital technologies in agriculture and rural areas: Status report*. FAO.

UN DESA. (2024). *World Population Prospects 2024*. United Nations Department of Economic and Social Affairs.

UNDP. (2021). *Blockchain for agri-food traceability*. United Nations Development Programme.

United Nations Development Programme. (2021). *Blockchain for agri-food traceability*. UNDP.

van Hilten, M., Ongena, G., & Ravesteyn, P. (2020). Blockchain for organic food traceability: Case studies on drivers and challenges. Wageningen University & Research.

WMO. (2024). *State of the Global Climate 2024*. World Meteorological Organization.

Wolfert, J., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big Data in Smart Farming – A review. *Agricultural Systems, 153*, 69–80. https://doi.org/10.1016/j.agsy.2017.01.023

World Bank (2023). Data-Driven Digital Agriculture. https://thedocs.worldbank.org/en/doc/1a163904ccb86646bf2e5d3d6f427f3d-0090012023/related/WB-DDAG-FA-web.pdf

World Bank. (2019). *Harnessing digital technologies to improve food system outcomes*. World Bank.

World Bank. (2021). *Digital agricultural profiles for Argentina, Kenya, Turkey and Viet Nam*. World Bank Group.

World Bank. (2024). *Climate-smart agriculture*. World Bank Group.

World Bank. (2024). *Transforming agriculture and food systems through data-driven digital agriculture* (Event brief). World Bank Group.

World Bank. (2025). *Commodity Markets Outlook*. The World Bank Group.

World Bank. (2025). *Digital agriculture roadmap playbook*. World Bank.

World Bank. (2025). *Global commodity markets outlook 2025*. World Bank Publications.

From Livestock 1.0 to Livestock 4.0: Digitalisation Adventure in Livestock

Gökçe ÖZDEMİR1[1]

[1] Department of Zootechnics and Animal Nutrition, Faculty of Veterinary Medicine, Sivas Cumhuriyet University, 58140, Sivas, TÜRKİYE gokceozdemir@cumhuriyet.edu.tr, ORCID NO: 0000-0003-1977-130X)

Abstract

Traditional animal husbandry methods, which were developed thanks to the first generation of labor-based animal husbandry, which has provided a significant accumulation of knowledge from the past to the present, still maintain their value. However, with the evolution that animal husbandry has undergone today, while maintaining animal welfare standards, it is transforming into a structure that aims to manage existing resources efficiently and to maximise animal production in environmentally sensitive, economic and sustainable conditions. The adventure of animal husbandry from traditional animal husbandry, which can be defined as Livestock 1.0, to the current process defined as Livestock 4.0, in which many other digital technologies such as data, sensor or digital are used, is discussed in many studies. In this study; adaptation of the development process from Industry 1.0 to Industry 4.0 to the agriculture and livestock sector, a brief summary of the historical evolution adventure from Livestock 1.0 to Livestock 4.0 with an in-depth look at the livestock sector was presented and it was aimed to contribute to the general discussion on this subject by examining the development and transformations it brought to animal husbandry and the latest situation of animal husbandry in the Livestock 4.0 process.
Key Words: *Animal husbandry, Industry 4.0, Agriculture 4.0, Livestock 4.0, Precision Livestock Farming*

Hayvancılık 1.0'dan Hayvancılık 4.0'a: Hayvancılıkta Dijitalleşme Serüveni

Özet

Geçmişten gelen ve başlangıçtan bu zamana kadar önemli bir bilgi birikiminin oluşmasını sağlayan emeğe dayalı ilk nesil hayvancılık sayesinde geliştirilmiş olan geleneksel hayvancılık yöntemleri hala değerini korumaktadır. Ancak günümüzde hayvancılık geçirmiş olduğu evrim ile, hayvan refahı standartlarını korurken, mevcut kaynakları verimli bir şekilde yönetmeyi ve çevreye duyarlı, ekonomik, sürdürülebilir koşullarda maksimum hayvansal üretimi hedefleyen bir yapıya dönüşmektedir. Hayvancılığın, Hayvancılık 1.0 diye tanımlanabilecek geleneksel hayvancılıktan, veri, sensor veya dijital daha birçok teknolojinin kullanıldığı Hayvancılık 4.0 olarak tanımlanan bugünkü sürece ulaşma serüveni birçok çalışmada ele alınmaktadır. Bu çalışmada; Endüstri 1.0'dan Endüstri 4.0'a gelişim sürecinin tarım ve hayvancılık sektörüne uyarlanması, hayvancılık sektörüne derinlemesine bir bakış ile Hayvancılık 1.0'dan Hayvancılık 4.0'a tarihsel evrim serüveninin kısa bir özeti sunuldu ve hayvancılığa kazandırdığı gelişim ve dönüşümler ile Hayvancılık 4.0 sürecinde hayvancılığın geldiği son durum incelenerek, bu konudaki genel tartışmaya katkıda bulunmak amaçlandı.
Anahtar Kelimeler: *Hayvancılık, Endüstri 4.0, Tarım 4.0, Hayvancılık 4.0, Hassas Hayvancılık*

Giriş

Hayvancılık endüstrisi, tarım ekonomisinin temeli olup, hayvansal kaynaklı ürün tüketiminin birincil kaynağını oluşturmaktadır (Jiang et al. 2023). Hayvansal kaynaklı ürünlere yönelik küresel talebin 2050 yılına kadar %70 artması beklenmektedir (Berckmans, 2017; Schillings et al., 2021; Yaman ve ark., 2021; Morrone et al. 2022). Bu ürünlere yönelik artan talep, hayvancılık ölçeğinde değişim ile çiftçileri faaliyetlerini genişletmeye ve büyütmeye zorlamaktadır (Norton et al., 2019; Morrone et al. 2022; Jiang et al. 2023). Hayvancılık sektöründe bu talep ve hayvansal ürünleri karşılayabilmek amacıyla hayvan başına maksimum verimlilik ve sürdürülebilirlik hedeflenerek, üretim alanlarının kontrol edildiği yoğun ve uzmanlaşmış teknolojik sistemlere doğru hızlı bir ilerleme yaşanmaktadır (Berckmans, 2017; Norton et al., 2019; Yaman ve ark., 2021). Hayvancılık devrimi diyebileceğimiz, bu süreç yavaş başlayıp hızlı bir büyüme, dönüşüm ve ilerleme göstermektedir. Hayvancılık sektörünün geçirdiği bu dönüşüm süreci, sanayi devrimi sonucunda şekillenen endüstriyel devrimlere gösterdiği benzerlik sebebiyle, endüstri devrimleri ile kıyaslanarak, Hayvancılık1.0'dan Hayvancılık 4.0'a kadar değişen aşamalar halinde bilim insanları bu önemli konuyu ele almaktadırlar. Ancak, hayvancılığın kendine özgü gereksinimleri ve hayvanların biyolojik özellikleri de dikkate alındığında hayvancılık evrelerinin kendine has bir yapı oluşturduğu bildirilmektedir (Norton et al., 2019; Yaman ve ark., 2021; Symeonaki et al., 2022; Kraft et al., 2022; Morrone et al. 2022; Gezici ve ark., 2023).

Hayvancılık sektörü; yoğunluk, büyüklük ve üretim sistemleri bakımından çeşitlilik ile karakterize farklı çiftlik yapılarına sahiptir. Bununla birlikte, bölgeden bölgeye doğal koşullardaki değişimlerle birlikte sosyo-kültürel, tarihsel ve ekonomik faktörler gibi birçok faktör hayvansal üretimi etkilemektedir. Bu nedenle, hayvancılıkta

işletme yapıları; çoğunlukla küçük ölçekli aile iş gücüyle yürütülmeye çalışılan işletmelerden büyük ölçekli yoğun üretim yapısına sahip teknolojinin tüm imkanlarından faydalanılan operasyonlara kadar değişen bir yelpaze içerisinde dağılım göstermektedir (Kraft et al., 2022; Jiang et al. 2023).
Hayvancılık sektörü, manuel emekten mekanizasyona, ardından hassas yönetimden akıllı sistem ve otonom operasyonlara doğru bir evrimleşme süreci geçirmiştir. Geçmişten gelen ve başlangıçtan bu zamana kadar önemli bir bilgi birikimin oluşmasını sağlayan emeğe dayalı ilk nesil hayvancılık sayesinde geliştirilmiş olan geleneksel hayvancılık yöntemleri hala değerini korumaktadır. Ancak günümüzde hayvancılık geçirmiş olduğu evrim ile, hayvan refahı standartlarını korurken, mevcut kaynakları verimli bir şekilde yönetmeyi ve çevreye duyarlı, ekonomik, sürdürülebilir koşullarda maksimum hayvansal üretimi hedefleyen bir yapıya dönüşmektedir. Hayvancılığın, Hayvancılık 1.0 diye tanımlanabilecek geleneksel hayvancılıktan, veri, sensor veya dijital daha birçok teknolojinin kullanıldığı Hayvancılık 4.0 olarak tanımlanan bugünkü sürece ulaşma serüveni birçok çalışmada ele alınmaktadır. Bu çalışmada; Endüstri 1.0'dan Endüstri 4.0'a gelişim sürecinin tarım ve hayvancılık sektörüne uyarlanması, hayvancılık sektörüne derinlemesine bir bakış ile Hayvancılık 1.0'dan Hayvancılık 4.0'a tarihsel evrim serüveninin kısa bir özeti sunuldu ve hayvancılığa kazandırdığı gelişim ve dönüşümler ile Hayvancılık 4.0 sürecinde hayvancılığın geldiği son durum incelenerek bu konudaki genel tartışmaya katkıda bulunmak amaçlandı.

Endüstri 1.0'dan 4.0'a

Endüstri Devrimi, insan faaliyetlerini tarımsal üretimden sanayileşmeye doğru taşıyan dört teknolojik devrimle gerçekleştiği bildirilmektedir (Morrone et al. 2022; Gezici ve ark., 2023). Endüstri 4.0 terimi, dördüncü sanayi devrimi vizyonunu ifade etmektedir (Kraft et al., 2022). Sanayini dört devrimi şu şekilde tanımlanmaktadır: Endüstri 1.0; 1900'lerin başına kadar olan dönemi kapsar ve insan faaliyetlerini yavaş ve küçük ölçekli üretimlerde, ürün yelpazesinin sınırlı ve ürün hacmine odaklanan merkezi bir kavramdır (Morrone et al. 2022; Gezici ve ark., 2023). Endüstri 2.0, 1950-1980'lere kadar devam eden dönemde sanayi mallarının hem hacim hem de çeşitlilik açısından arttığı bir dönemdir. Elektrikli, elektronik, mekanik cihazlar ve motorlu araçların kullanımının yaygınlaştığı bir süreçtir (Morrone et al. 2022; Gezici ve ark., 2023). Endüstri 3.0 ise 1980'lerden günümüze kadar devam eden dönemdeki teknolojik gelişmelerle karakterizedir ve özellikle elektronik endüstrisinde önemli etkiler yaratmıştır (Morrone et al. 2022; Gezici ve ark., 2023). Endüstri 4.0 terimi, 2013 yılında kamuoyuna tanıtılmıştır. Endüstri 4.0'ın temel ön koşulu, karmaşık sistemlerin dinamik yönetimi için gerçek zamanlı, yetenekli, akıllı, yatay ve dikey bir insan, makine, nesne BT sistemleri ve yapay zeka dijitalleşme ve yenilikçi teknolojilerin kullanıldığı bir dönemi temsil etmektedir (Kraft et al., 2022; Morrone et al. 2022). Endüstri 4.0, küresel ekonomi ve üretim sistemlerinde radikal bir değişim olarak kabul edilmektedir (Lui et al. 2021; Morrone et al. 2022; Gezici ve ark., 2023).

Tarım 1.0'dan 4.0'a

İnsanoğlu, eski zamanlardan beri hayatta kalmak için yiyecek elde etmek için toprakları ekmiş ve hayvanları yetiştirmiştir. Endüstri 4.0'ın 2030 vizyonu özerkliğe, iş bilirliğine ve sürdürülebilirliğe odaklanmakta ve tarımsal üretim için de önem taşımaktadır. Endüstri 4.0 teknolojilerinin ve kavramlarının tarıma aktarılması, Tarım 4.0 teriminin ortaya çıkmasına ilham kaynağı olup, yaklaşık 2018'den beri bu kavram tartışılmaktadır (Goller et al., 2021; Vázquez-López et al. 2021; Morrone et al. 2022; Kraft et al., 2022). Neolitik çağadan bu yana 10.000 yılda Tarım Devrimi'nde çiftçiler inanılmaz şeyler başarmıştır. Bu zaman diliminin büyük çoğunluğunda, kas gücü, mekanik, yaratıcılık ve bazı ilkel yetiştirme becerileri kullanılmıştır (Fraser and Campbel, 2019; Zhai et al. 2020; Symeonaki et al., 2022). Tarım 1.0'dan uzun vadeli ve ilerleyen bir sürecin sonucunda Tarım 4.0'a gelişmiştir. Tarım sektörünün, birincisi makineleşme (Tarım 2.0), ikincisi yeşil devrim (Tarım 3.0), günümüzde daha büyük miktarda veriye erişim nedeniyle çiftlik bilgi sistemlerinin artmasıyla geliştirilmiş modern tarım devriminin üçüncü dalgası haline gelen Hassas Tarım (Tarım 4.0) ile bir dizi dönüşümden geçtiği bildirilmektedir (Saiz-Rubio and Rovira-Más, 2020; Zhai et al. 2020; Symeonaki et al., 2022). Tarım 1.0, geleneksel tarım dönemi olan temelde insan ve hayvan gücüne dayanmaktadır. Bu dönemde, tarımsal faaliyetlerinde basit aletler kullanılmış olup, verimlilik oldukça düşük düzeyde kalmıştır (Kovács and Husti, 2018; Zhai et al. 2020; Lui et al. 2021; Symeonaki et al., 2022).
Sanayi Devriminin etkisiyle başlayan büyük tarım devrimi (Fraser and Campbel, 2019) olan endüstriyel tarım dönemi (Tarım 2.0), 1950'lerin sonunda başlayıp, manuel çeşitli tarım makinelerinin, motorlu araçların ve bol miktarda kimyasal maddelerin kullanıldığı süreç olarak tanımlanmaktadır. Tarım 2.0 dönemi, çiftlik işlerinin verimliliğini ve üretkenliğini önemli ölçüde artırıldığı ancak, ekolojik çevrenin tahribatı, kimyasal kirlenme, aşırı güç tüketimi ve doğal kaynakların israfı gibi zararlı sonuçların ortaya çıktığı bir dönemdir (Kovács and Husti, 2018; Zhai et al. 2020; Lui et al. 2021; Symeonaki et al., 2022).
Tarım 3.0, 1990'lardan itibaren şekillenen, bilişim ve elektronik alanlarında hızlı gelişmelerin yaşandığı, bilgisayar programları ve robotik teknikler, tarım makinelerinin operasyonları verimli ve akıllı bir şekilde gerçekleştirildiği dönemi tanımlamakta kullanılmaktadır. Tarım 2.0'dan kalan sorunlar çok ileri gitmeden önce Tarım 3.0'da stratejiler düzenlenmiştir. Tarım makinelerinin kullanımının yaygınlaştırılması, kimyasal kullanımının azaltılması,

sulamada hassasiyetinin artırılması gibi çözümlerin hayata geçirildiği bir dönemdir (Kovács and Husti, 2018; Fraser and Campbel, 2019; Zhai et al. 2020; Lui et al. 2021; Symeonaki et al., 2022).
2010'lardan sonra tanımlanan, Tarım 4.0 (Akıllı Tarım veya Hassas Tarım dönemi) yeni bir tarım devrimi olarak tanımlanmaktadır (Kovács and Husti, 2018; Fraser and Campbel, 2019). Tarım 4.0, günümüzde, Nesnelerin İnterneti (IoT), Büyük Veri (Big Data), Yapay Zeka (AI), Bulut Bilişim (Cloud Computing), Uzaktan Algılama (Remote Sensing) gibi güncel teknoloji ile biyoteknoloji yöntemlerinin kullanılması sonucunda gelişmiş bir süreçtir. Bu teknolojilerin uygulanması ile tarımsal faaliyetlerin verimliliği önemli ölçüde artırılabilmektedir. Tarım 4.0, tüm alanlardan gelen verilerin toplandığı ve işlendiği, çiftçiler için net bir görüş ve karar destek sağlandığı bir aşamadır (Zhai et al. 2020; Symeonaki et al., 2022 Lui et al. 2021). Gerçekten de Tarım 4.0, insansız operasyonlar ve otomatik karar verme sistemlerinden oluşan bir sonraki tarımsal evrimin önünü açmaktadır (Jo et al., 2018; Vázquez-López et al. 2021; Lui et al. 2021; Morrone et al. 2022; Kraft et al., 2022). Teknoloji odaklı bu yaklaşım, çevre, teknoloji ve insanlar arasında yakın bir bağlantı kurarak, sürdürülebilirlik ve dayanıklılık ihtiyaçlarına odaklanan yeni tarım ve hayvancılık sistemlerinin geliştirilmesine zemin hazırlamaktadır (Bahlo et al., 2019; Kraft et al., 2022).

Hayvancılık 1.0'dan 4.0'a

Endüstri 4.0 için oluşturulan standart bir tanım veya yapı sonradan araştırmacılar tarafından düzenlenerek, diğer sektörler üzerindeki etkileri tartışılmıştır. Endüstri 4.0'ın, tarım sektöründeki etkileri değerlendirilerek, literatür analizi yoluyla bir çerçeve geliştirilmiş ve hayvancılık üzerindeki mevcut etkileri ve olanakları bazı araştırmacılar tarafından değerlendirilmiştir (Zhai et al. 2020; Yaman ve ark., 2021; Symeonaki et al., 2022; Kraft et al., 2022). Özellikle Endüstri 4.0'ın sağladığı faydaların büyük bir kısmının belirli uyarlamalarla hayvancılığa uygulanabileceği ve hayvancılığın iyileştirilmesine katkı sağlayabileceği bildirilmektedir (Kraft et al., 2022). Ancak, hayvancılık; endüstriyel üretimden farklıdır: canlı hayvanların ihtiyaçları karşılamak zordur, hayvanlar "materyal" değildir ve hayvanların kendi etik kimliği vardır. Hayvancılıkta, Endüstri 4.0'ın potansiyel faydalarını tartışırken, bu noktaların dikkate alınmasının gerekliği özellikle vurgulanmaktadır (Kraft et al., 2022).
Hayvancılık sektörü, tarım ekonomisinin temelidir ve hayvansal kaynaklı ürünlerin birincil kaynağını oluşturmaktadır. Hayvansal gıdaya yönelik artan talep, hayvancılık ölçeğinde önemli bir değişime sebep olmaktadır. Günümüzde hayvancılık, yetiştiricilik ve üretim sistemi uygulamalarında çiftçilerin gözlemlerine, yargılarına ve deneyimlerine dayanan geleneksel ekstansif yetiştiricilik modellerinden, modern büyük ölçekli hayvancılığın gerekliliklerini yerine getiren entansif yetiştiricilik modelini benimseyen, bilgi ve teknolojilerinin desteğiyle yürütülen modern hayvancılığa doğru kaçınılmaz bir ilerleme göstermektedir (Kraft et al., 2022; Jiang et al. 2023). Hayvancılık, insanlık tarihi boyunca sürekli evrilen bir faaliyet olup, bu durum dört evrede ele alınmaktadır (Norton et al., 2019; Zhai et al. 2020; Yaman ve ark., 2021; Symeonaki et al., 2022; Jiang et al. 2023).
Hayvancılık 1.0 (Ekstansif hayvancılık) olarak tanımlanabilen ilk evrede, çiftçiler ve hayvanları, doğrudan ve yoğun bir etkileşim içerisindedir ve hayvan sayıları genellikle daha az olup sürü boyutları küçük ve verimlilik düşüktür. Eski çağlardan beri Tarım 1.0'ın parçası olarak, hayvan yetiştiriciliği, hayatta kalabilmek için insanların besin ihtiyaçlarını karşılamak amacıyla geniş otlaklar da hayvan yetiştirdikleri bir faaliyettir (Norton et al., 2019). Bu dönemde, hayvancılık ilkel şartlarda basit aletlerle, insan emeği ile yürütülmektedir (Zhai et al. 2020; Yaman ve ark., 2021; Symeonaki et al., 2022). Bu ilk evrenin, mera ve yaylalarda yapılan ekstansif hayvancılığı ifade ettiği bildirilmektedir (Yaman ve ark., 2021).
Hayvancılık 2.0 (Entansif hayvancılık), hayvancılıkta endüstriyel yöntemlere geçişin başladığı bir dönemdir. Hayvancılıkta, özellikle kümes hayvanı ve domuz üretimi gibi çok sayıda hayvanın bulunduğu yoğun üretim alanları ön plana çıkmıştır (Norton et al., 2019; Zhai et al. 2020; Symeonaki et al., 2022). Bu dönemde, yem ve beslemenin önemi anlaşılmış, genetik ıslah çalışmaları ile hayvan ırkları ve sürülerde genetik iyileştirmeye yönelik çalışmalar yoğunlaşmıştır (Yaman ve ark., 2021). Hayvancılıkta, besleme prensiplerinde gelişmeler ile mineral madde ve vitamin gibi mikro besin unsurların önemi üzerinde durularak, yeni biyoteknoloji yöntemleri kullanılmaya bu dönemde başlanmış ve hayvancılıkta üretkenlik hedeflenmiştir (Yaman ve ark., 2021). Bu dönemde, bilinçli ürün rotasyonu, daha iyi ekipman kullanımı ve hayvanların dikkatli bir şekilde yetiştirilmesi üretimi artırmaya yardımcı olmuştur (Fraser and Campbel, 2019).
Hayvancılık 3.0 (Modern hayvancılık), 1970'lerden bu yana önemli ölçüde gelişmiştir. Başlangıçta inekler için bireysel elektronik süt ölçerler gibi sistemlerle başlayan süreç zamanla hayvan hareketlerinin takibi ile kızgınlık tespiti ve geviş getirme aktivitesi izleme gibi çalışmalarla genişletilmiştir (Morrone et al. 2022; Jiang et al. 2023). Ancak, yetiştiricilerin çiftliklerde hayvanlarla doğrudan etkileşim kurmasının zorlaştırdığı bir süreçtir. Bu sorunun çözümü ise yine teknolojinin hızlı gelişimi sayesinde hayvan ile yetiştirici arasında daha iyi bir etkileşim kurması ile mümkün kılınmaktadır (Norton et al., 2019; Symeonaki et al., 2022). Bu dönem; teknolojik uygulamaların otomasyonla entegre edilen sistemlerinin kullanılmaya başlandığı ve döl testi, hayvan ıslahı alanında biyteknoloji yöntemlerinin yaygınlaştığı bir süreç olarak tanımlanabilmektedir (Yaman ve ark., 2021).
Hayvancılık 4.0 (Hassas/Akıllı Hayvancılık), 1990'ların başından itibaren hayvancılık üretiminde bilgi ve iletişim teknolojileri destekli yönetim sistemleri üzerine araştırmaların arttığı bir dönemdir. Bilişim ve elektronik alanlarında güncel teknolojilerdeki hızlı gelişmelerle ortaya çıkan hassas tarım döneminin hayvancılığa yansıdığı

bir dönemdir. Hayvancılık 4.0, hayvancılığın veriye dayalı yeni bir devrim ve dönüşümden geçtiği bir dönemdir (Norton et al., 2019; Zhai et al. 2020; Lui et al. 2021; Yaman ve ark., 2021; Symeonaki et al., 2022). Bu dönemin odak noktası, hayvanlarla doğrudan etkileşim kurmaktan ziyade, yetiştiricilere hayvanları hakkında daha objektif bilgiler sunan karar destek sistemleri oluşturarak, ekonomik ve sürdürülebilir bir hayvancılık yaklaşımı geliştirmektir (Norton et al., 2019; Zhai et al. 2020; Lui et al. 2021; Yaman ve ark., 2021; Symeonaki et al., 2022). Bu sistemde merkezi bir bilgisayar, makineleri ve çalışanları kontrol etmekte ve daha kapsamlı ve dinamik bir üretim süreci sağlanmaktadır. Bu sistemin temelinde; gerçek zamanlı çiftlik yönetimi, veri toplama, iletme, analizi, erken uyarı, otomatik kontrol ve karar verme süreçlerinden oluşan akıllı kullanımını sağlayan cihaz optimizasyonu hedeflenmekte ve radyo frekansı tanımlama, sensör, sensör ağı teknolojileri ve internet iletişimi yer almaktadır. (Goller et al., 2021; Vázquez-López et al. 2021; Yaman ve ark., 2021; Lui et al. 2021; Morrone et al. 2022; Kraft et al., 2022; Gezici ve ark., 2023).

Teknoloji odaklı Endüstri 4.0, odağını tekrar insana, sürdürülebilirlik ve dayanıklılık ihtiyaçlarını yönelten yeni bir yaklaşım olan Endüstri 5.0 doğru evrilmekte olduğu bildirilmektedir (Kraft et al. 2022). Yapay zeka teknolojilerinin kullanılacağı son evre olan İleri Hayvancılığın kavşağında bulunan hayvancılık, yeni bir yaklaşım olan ***Hayvancılık 5.0*** (İleri Hayvancılık) versiyonu ile çevre, teknoloji ve insanlar arasında yakın bir bağlantı olduğu için tarım ve hayvancılık alanlarında özellikle ilgi çektiği bildirilmektedir (Saiz-Rubio and Rovira-Más, 2020; Yaman ve ark., 2021; Kraft et el., 2022; Gezici ve ark., 2023).

Hayvancılık 4.0, Hassas Hayvancılık

Hayvancılık 4.0, hayvan başına yaklaşımı temel almaktadır. Bu dönemde, hayvancılık, hayvan verimliliğini, çevresel etkileri, sağlık ve refah parametrelerini sürekli, gerçek zamanlı ve otomatik bir şekilde izleyip kontrol ederek çiftçileri hayvancılık yönetiminde desteklemek üzere tasarlanan teknolojileri yönelim kazanmaktadır (Berckmans, 2014; Schillings et al., 2021; Morrone et al. 2022; Kraft et al., 2022).

Hassas hayvancılıkta, bu amaçlar doğrultusunda üretim süreçlerinde ortaya çıkan karmaşık sorunları çözmek için daha fazla veri sistematik olarak toplanması, kayıt ve analiz edilmesi gerektirmektedir. Hassas hayvancılıkta; hayvanlarla ilgili düzenleme yapılabilmesi ve tahmin ve öngörülerde bulunabilmek için hava durumu, hava kalitesi, hayvan ses sinyalleri, görsel hayvan davranışları gibi çok sayıda farklı veri kümeleri toplanır. Yıl boyunca geniş hacimli büyük verilerin işlenmesi, depolanması, saklanması ve analiz edilmesi için daha farklı teknolojilere ihtiyaç duyulmaktadır. Büyük Veri (Big Data), Yapay Zeka (AI), Bulut Bilişim (Cloud Computing), Uzaktan Algılama (Remote Sensing) ve Blokzincir (Block Chain) gibi teknolojiler devreye girmektedir (Norton et al., 2019; Kovács and Husti, 2018; Lui et al. 2021; Vázquez-López et al. 2021; Symeonaki et al., 2022; Morrone et al. 2022; Kraft et al., 2022; Jiang et al. 2023). Bu dönemde bazı uygulamalar, örneğin, hayvan tanımlama ve takip sistemleri (derin öğrenme tabanlı, RFID transponder, boluslar, çipler ve bilgisayar görüşü tabanlı yöntemler gibi), otomatik sağım sistemleri, kızgınlık tespiti (ivmeölçer, adım sayımı, hareket hızlanması, geviş getirme sıklığı, yatma süresi), hastalık tespiti (topallık, solunum hastalıkları kızılötesi termografi yöntemleri gibi), hayvan performansı su ve yem takibi yöntemleri, hayvan davranışları takibi ile sürü ve hayvan refahı izlenmesi gibi birçok alanda Hayvancılık 4.0 versiyonuna ait teknolojik uygulamalar aktif bir şekilde hayata geçirilmiştir (Berckmans, 2017; Kovács and Husti, 2018; Norton et al., 2019; Vázquez-López et al. 2021; Yaman ve ark., 2021; Symeonaki et al., 2022; Morrone et al. 2022; Kraft et al., 2022; Jiang et al. 2023).

Hayvancılık 4.0 teknolojileri genellikle, orta ve büyük ölçekli çiftliklerdeki barınak içi üretim modellerine entegre edilmiş olsa da, dijital araçların ve sahip olduğu potansiyellerin küçük ölçekli çiftlikler ve mera yetiştiriciliği için de uygun olduğunu belirtmek gerekir. Taşınabilir sensörler, hayvanların GPS konumlandırması ve çeşitli yazılım uygulamaları, hayvancılık ekonomisinin bu alanlarında da dijital ilerlemelerin kullanımına olanak sağlayacaktadır (Berckmans, 2017; Kovács and Husti, 2018; Symeonaki et al., 2022; Kraft et al., 2022).

Bazı Endüstri 4.0 faydaları, Hayvancılık 4.0 nesline doğru daha da geliştirilmesi için potansiyel sunmaktadır (Kraft et al., 2022). Endüstriyel ve hayvancılık kullanım örnekleri arasındaki temel farklılıklar nedeniyle, faydaların bir kısmının uyarlanması gerekmektedir. Bireysel canlı hayvanların varlığı ve hayvancılığın güçlü çevresel etkisi, dijital bireyselleştirmenin ve talep yöneliminin rolünü etkilemektedir. Ancak, Endüstri 4.0 faydalarının bazıları hayvancılık için yeniden tanımlanması gerekmektedir ve bazı özellikler ise hayvancılığa nadiren uygulanabilir ve çok az ihtiyaç duyulabileceği bildirilmektedir (Kraft et al., 2022).

Sonuç

Hayvancılık sektörü, insanlık tarihi boyunca geleneksel yöntemlerden günümüzün ileri teknolojik uygulamalarına doğru katmanlı bir dönüşüm sürecinden geçmiştir. Bu evrim, küresel gıda talebinin artması, sürdürülebilirlik kaygıları ve çevresel baskılar gibi faktörlerle hız kazanmıştır. Bu dönüşüm genellikle Hayvancılık 1.0'dan Hayvancılık 4.0'a kadar uzanan yolculuğu, yerel ve basit yöntemlerden küresel ve akıllı sistemlere doğru evrilen aşamalardan oluşmaktadır. Hayvancılık 1.0 geleneksel, insan ve hayvan gücüne dayalı bir yaklaşımdan başlarken, Hayvancılık 4.0, modern sensörler, veri analizi ve yapay zeka gibi ileri teknolojileri kullanarak hayvan refahını, sağlığını ve üretkenliğini optimize etmeyi amaçlayan, çiftçi ve hayvan arasındaki bilgi boşluğunu kapatan akıllı ve sürdürülebilir bir yönetim felsefesini temsil etmektedir. Türkiye'de hayvancılık sektöründe üretim ağırlıklı olarak Hayvancılık 2.0 sonu Hayvancılık 3.0 aşamasında olduğunu ve Hayvancılık 4.0 seviyesinde yenilikçi girişimleri benimseyen yeni üretim sistemlerinin de yaygınlaştığı yönünde bir genelleme yapmak yanlış olmayacaktır. Gelecekte, Hayvancılık 5.0 ile robotik, yapay zeka ve insan odaklı teknolojilerin daha da öne çıkması beklenmektedir. Bu dönüşümün başarısı ise, yetiştiricilerin ve toplumun bu yeni sistemlere adaptasyon sağlayıp eğitim süreçleriyle de hayata geçirilmesi ve yaygınlaştırılmasının sağlanabileceği düşünülmektedir.

Kaynaklar

Jiang, B., Tang, W., Cui, L., & Deng, X. (2023). Precision Livestock Farming Research: A Global Scientometric Review. Animals, 13:2096. https://doi.org/10.3390/ani13132096

Berckmans, D. (2017). General introduction to precision livestock farming. Animal Frontiers, 7(1): 6-11, https://doi.org/10.2527/af.2017.0102

Schillings, J., Bennett, R., & Rose, D.C. (2021). Exploring the Potential of Precision Livestock Farming Technologies to Help Address Farm Animal Welfare. Front. Anim. Sci. 2:639678. doi: 10.3389/fanim.2021.639678

Yaman, H., Sungur, O., & Dulupçu, M.A. (2021). Dünyada Tarım ve Hayvancılığın Dönüşümü: Teknolojiye Dayalı Uygulamalar ve Devrimler. Tarım Ekonomisi Dergisi, 27(1):123-133, DOI 10.24181/tarekoder.938925

Morrone, S., Dimauro, C., Gambella, F., & Cappai, M.G. (2022). Industry 4.0 and Precision Livestock Farming (PLF): An up to Date Overview across Animal Productions. Sensors. 22(12):4319. https://doi.org/10.3390/s22124319

Norton, T., Chen, C., Larsen, M.L.V., & Berckmans, D. (2019). Review: Precision livestock farming: building 'digital representations' to bring the animals closer to the farmer. Animal, 13(12):3009-3017, https://doi.org/10.1017/S175173111900199X.

Symeonaki, E., Arvanitis, K.G., Piromalis, D., Tseles, D., & Balafoutis, A.T. (2022). Ontology-Based IoT Middleware Approach for Smart Livestock Farming toward Agriculture 4.0: A Case Study for Controlling Thermal Environment in a Pig Facility. Agronomy, 12:750. https://doi.org/10.3390/agronomy12030750

Kraft, M., Bernhardt, H., Brunsch, R., Büscher, W., Colangelo, E., Graf, H., Marquering, J., Tapken, H., Toppel, K., & Westerkamp, C, et al. (2022). Can Livestock Farming Benefit from Industry 4.0 Technology? Evidence from Recent Study. Applied Sciences. 12(24):12844. https://doi.org/10.3390/app122412844

Gezici, M., Ünay, E., Üstün, K., & Coşkun, M.İ. (2023). Hayvancılık İşletmelerinde Teknoloji Kullanımı ve Ekonomik Verimlilik. Ziraat Mühendisliği, 377:26-32. https://doi.org/10.33724/zm.1281613

Jo, S.K., Park, D.H., Park H. & Kim, S.H. (2018). Smart Livestock Farms Using Digital Twin: Feasibility Study. 2018 International Conference on Information and Communication Technology Convergence (ICTC), Jeju, Korea (South), 2018, pp. 1461-1463, doi: 10.1109/ICTC.2018.8539516.

Vázquez-López, A., Barrasa-Rioja, M., & Marey-Perez, M. (2021). ICT in Rural Areas from the Perspective of Dairy Farming: A Systematic Review. Future Internet, 13:99. https://doi.org/10.3390/fi13040099

Liu, Y., Ma, X., Shu, L., Hancke, G.P. & Abu-Mahfouz, A.M.. (2021). From Industry 4.0 to Agriculture 4.0: Current Status, Enabling Technologies, and Research Challenges.in IEEE Transactions on Industrial Informatics. 17(6): 4322-4334, doi: 10.1109/TII.2020.3003910.

Goller, M., Caruso, C., & Harteis, C. (2021). Digitalisation in agriculture: knowledge and learning requirements of German dairy farmers - In: International journal for research in vocational education and training 8(2):208-223 - URN: urn:nbn:de:0111-pedocs-233236 - DOI: 10.25656/01:23323

Saiz-Rubio, V., & Rovira-Más, F. (2020). From Smart Farming towards Agriculture 5.0: A Review on Crop Data Management. Agronomy, 10:207; doi:10.3390/agronomy10020207

Zhai, Z., Martínez, J.F., Beltran, V., & Martínez, N.L. (2020). Decision support systems for agriculture 4.0: Survey and challenges. Computers and Electronics in Agriculture, 170:105256, https://doi.org/10.1016/j.compag.2020.105256.

Fraser, E.D.G. & Campbell, M. (2019). Agriculture 5.0: Reconciling Production with Planetary Health. One Earth, 1(3):278 - 280

Kovács, I., & Husti, I. (2018). The role of digitalization in the agricultural 4.0–how to connect the industry 4.0 to agriculture?. Hungarian agricultural engineering, (33):38-42.

Berckmans, D. (2014). Precision livestock farming Technologies for welfare management in intensive livestock systems. Rev. sci. tech. Off. int. Epiz., 3(1):189-196

Bahlo, C., Dahlhaus, P., Thompson, H., & Trotter, M. (2019). The role of interoperable data standards in precision livestock farming in extensive livestock systems: A review. Computers and Electronics in Agriculture, 156:459-466, https://doi.org/10.1016/j.compag.2018.12.007.