MEETCON- X

4. INTERNATIONAL CONGRESS ON SCIENTIFIC RESEARCH



MeetCon conference

September 01-04, 2026

EDITOR:

Assoc. Prof. Dr. Nazlı Deniz CERİDHAN

www.meetcon.org

PROCEEDINGS BOOK

MEETCON - X

IV. INTERNATIONAL CONGRESS ON SCIENTIFIC RESEARCH

September 01-04, 2026 / Ankara, Türkiye

Editor

Assoc. Prof. Dr. Nazlı Deniz CERIDHAN

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CONGRESS ID

TITLE OF CONGRESS

MEETCON - X

IV. INTERNATIONAL CONGRESS ON SCIENTIFIC RESEARCH

PARTICIPATION

Keynote & Invited

DATE - PLACE

September 01-04, 2026 / Ankara, Türkiye

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MEETCON CONFERENCE

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Dr. Xatirə ƏLİYEVA, Azerbaijan State Pedagogical University, Azerbaijan

Dr. Yunus DOĞAN, Fırat University, Türkiye

Dr. Zongxian FENG, Xi`an Jiatong University, China

PARTICIPATING COUNTRIES (11)

Türkiye, Azerbaijan, Pakistan, Romania, Moldova, Algeria, Vietnam, Nigeria, Iran, India, Morocco

TOTAL PAPERS: 47

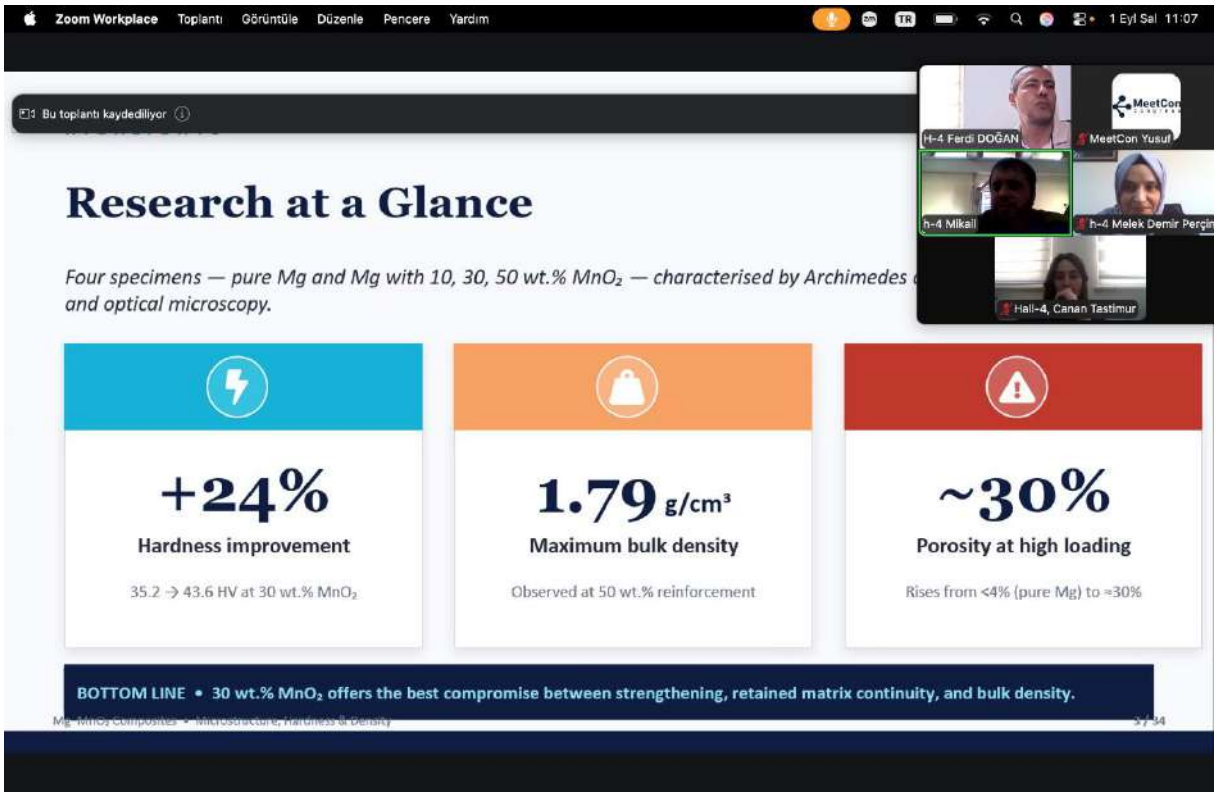
The number of papers from foreign countries: **25**

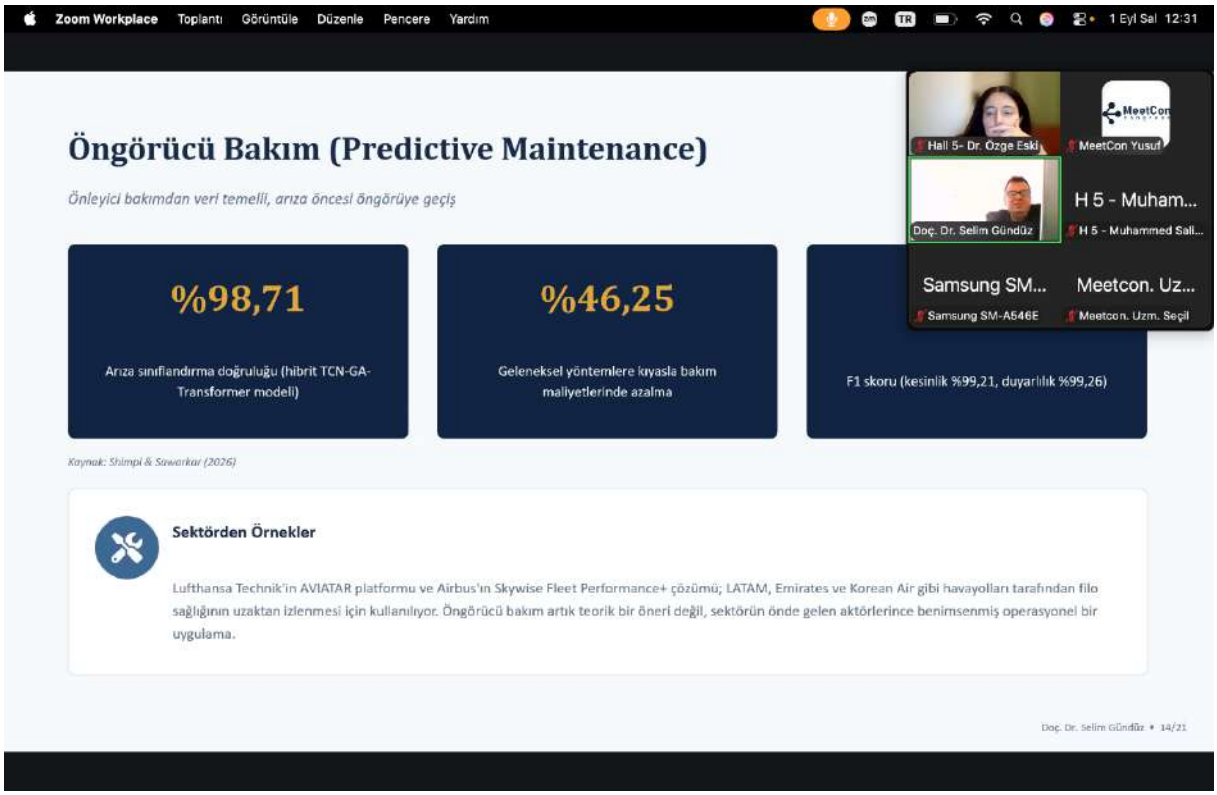
The number of papers from Türkiye: **22**

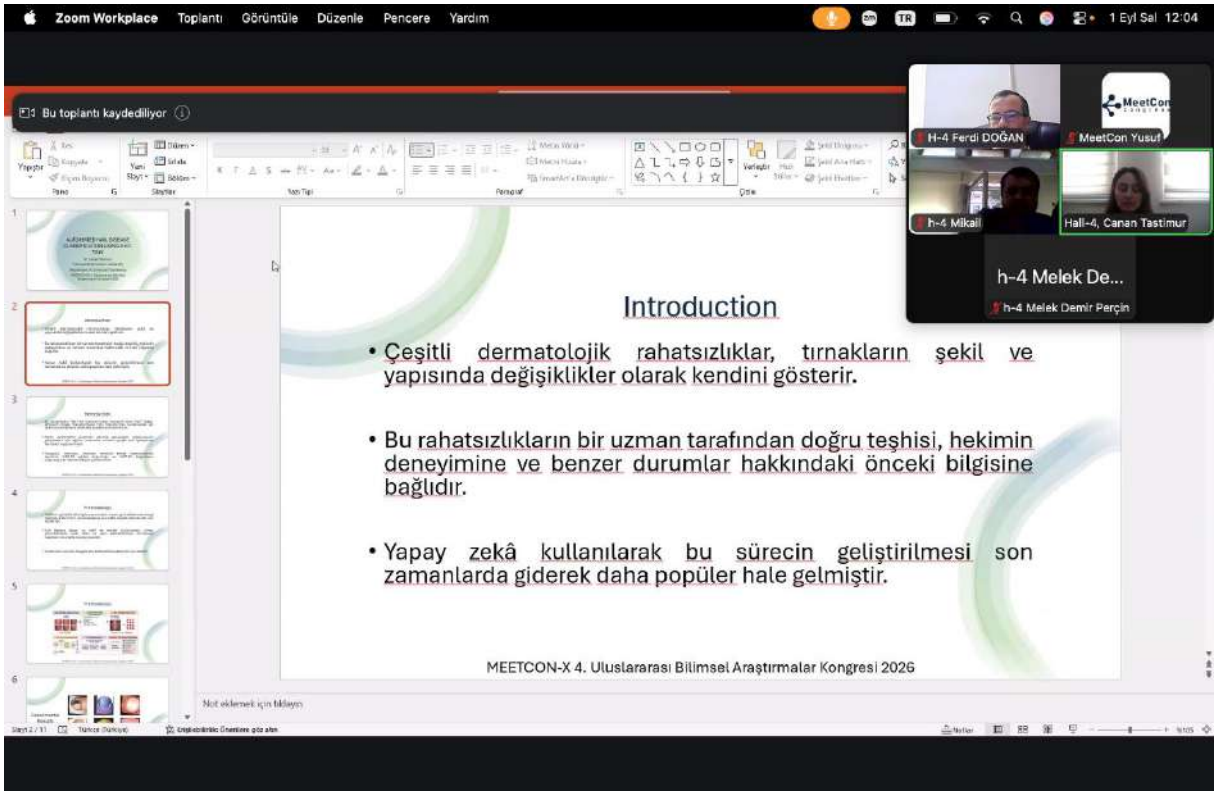
LANGUAGES

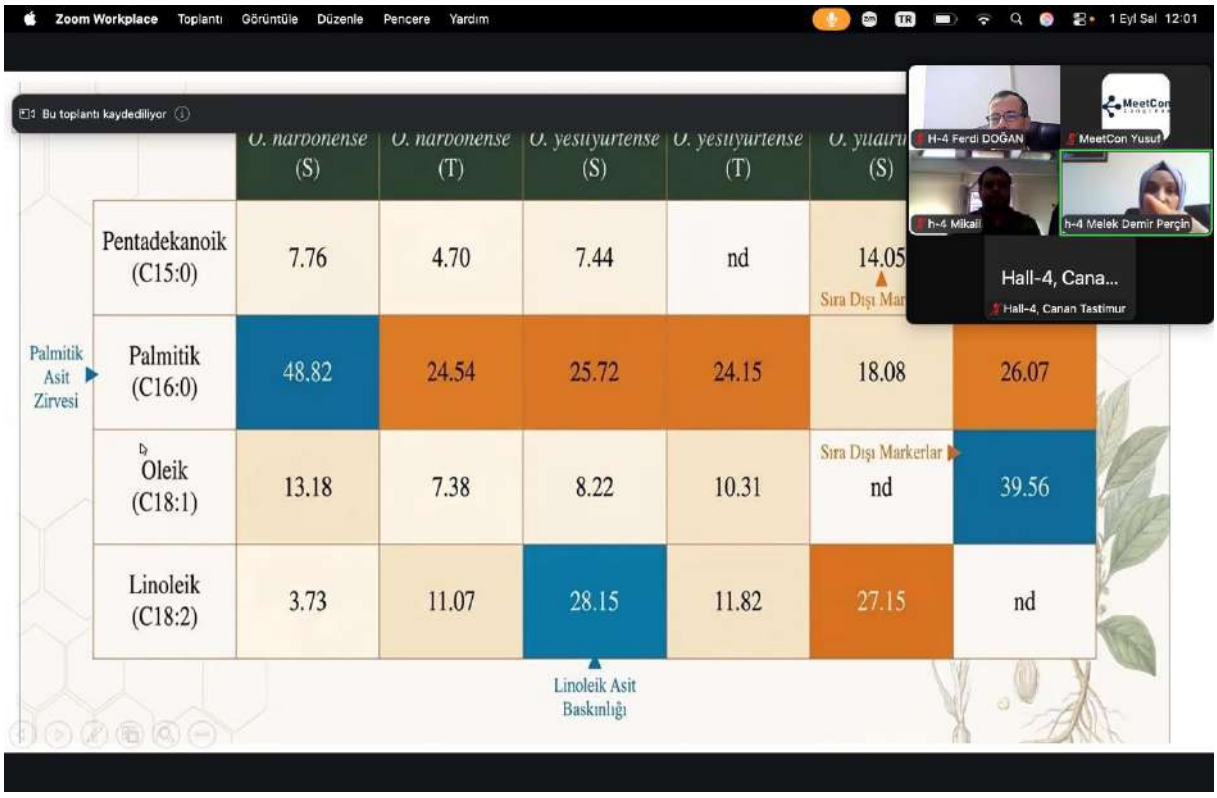
Turkish, English

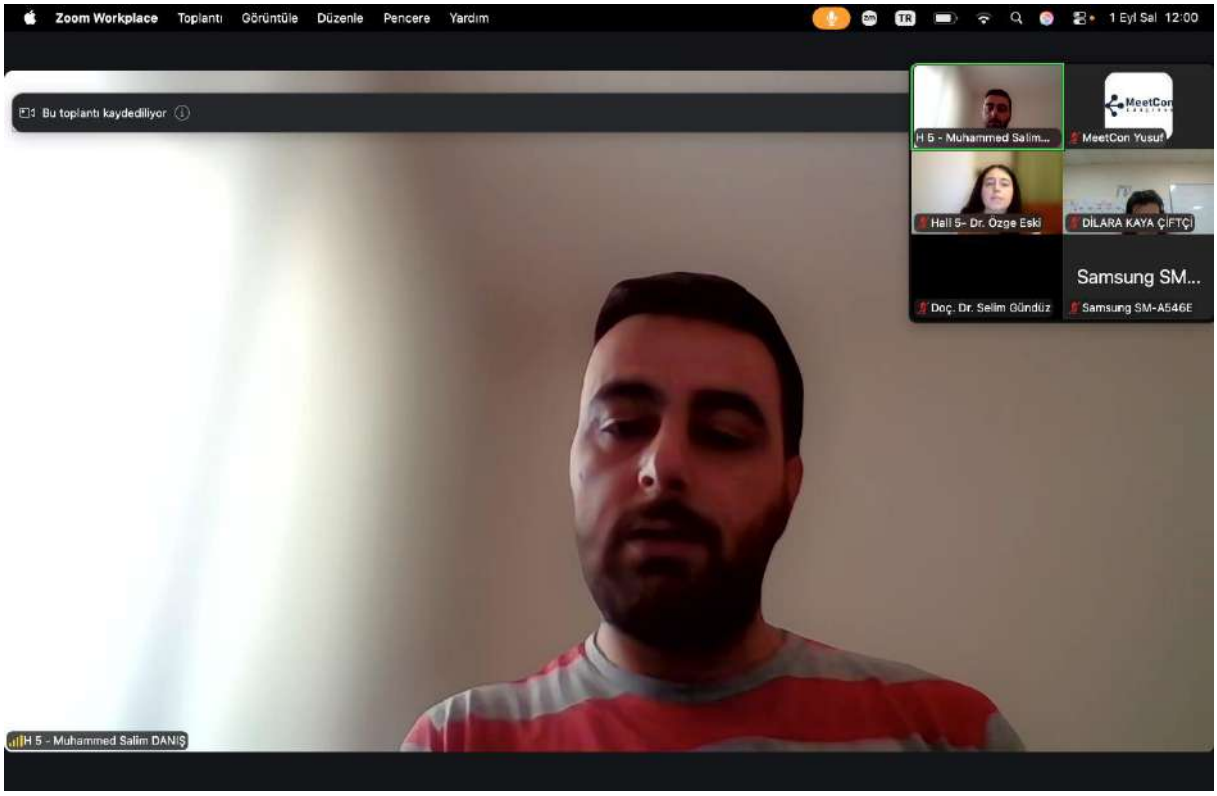
PHOTO GALLERY

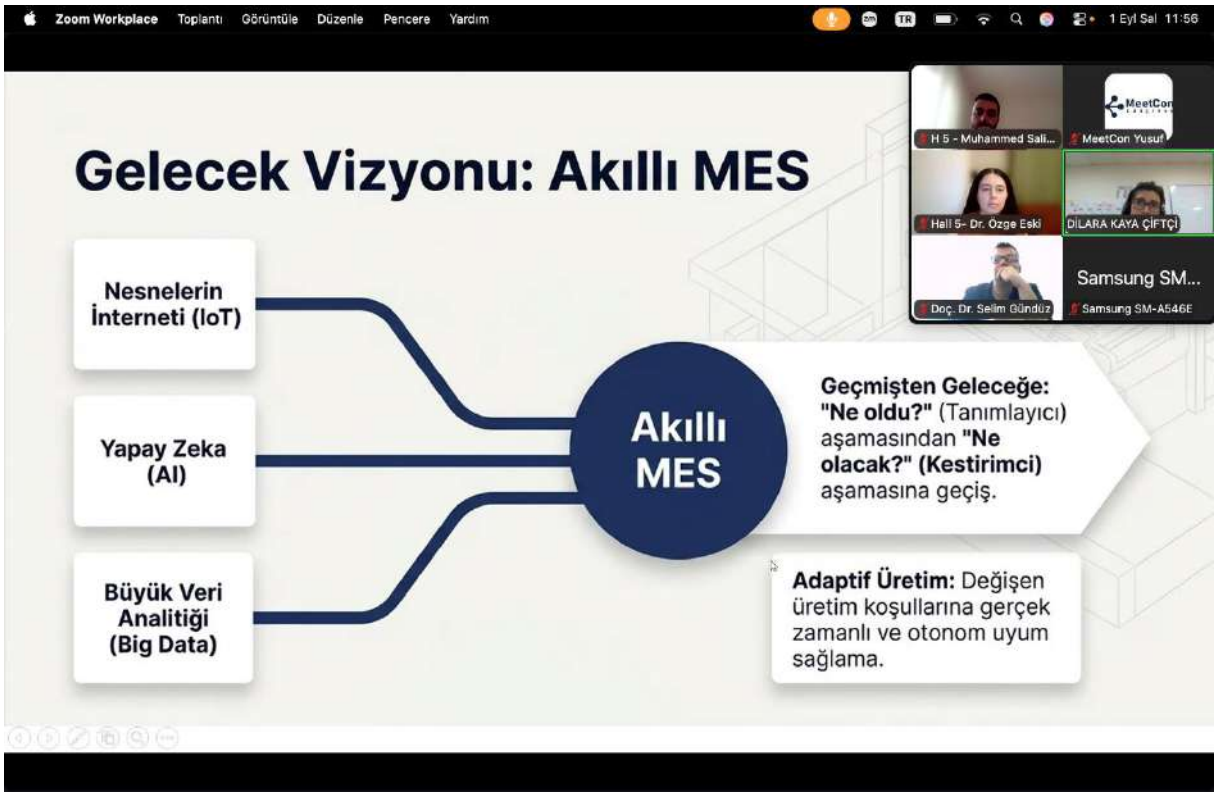




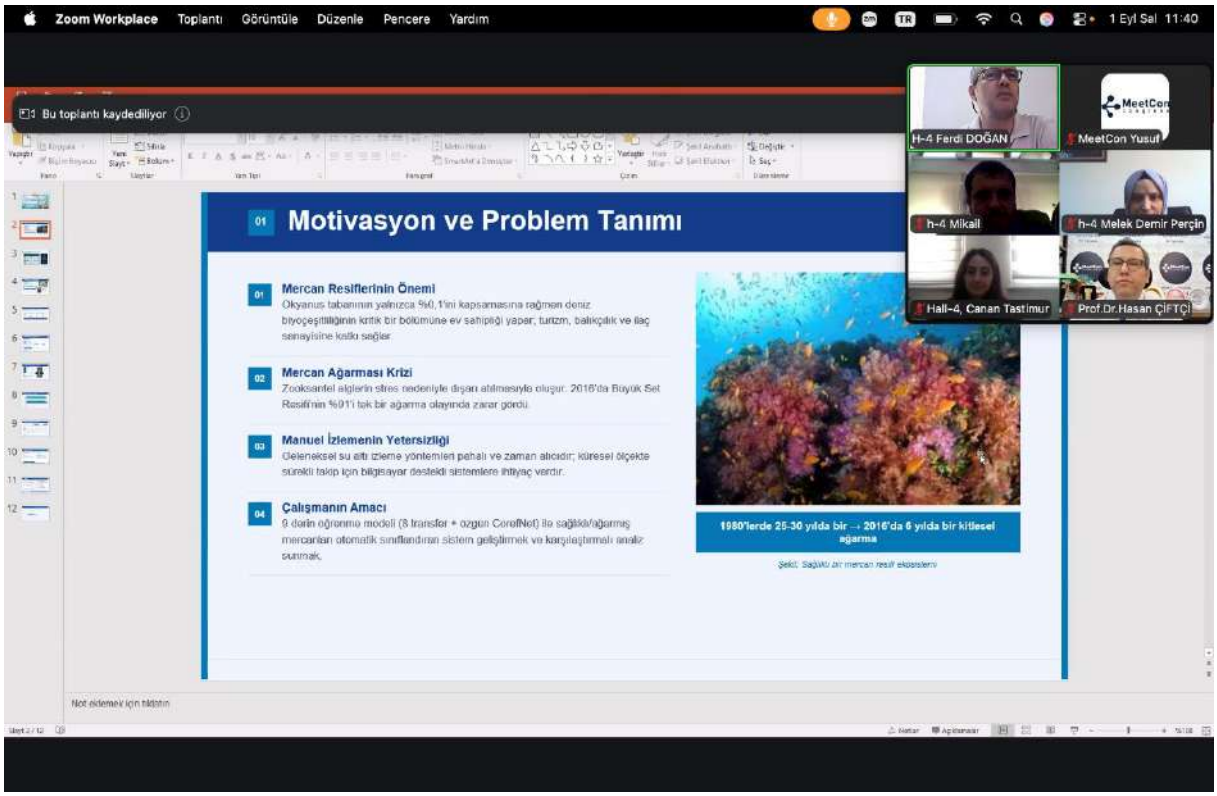

Zoom Workplace Toplantı Görüntüle Düzenle Pencere Yardım
1 Eyl Sal 12:04
Bu toplantı kaydediliyor
H-4 Ferdi DOĞAN
MeetCon Yusuf
h-4 Mikail
Hall-4, Canan Tastimur
h-4 Melek De...
h-4 Melek Demir Perçin
Introduction
• Çeşitli dermatolojik rahatsızlıklar, tırnakların şekil ve yapısında değişiklikler olarak kendini gösterir.
• Bu rahatsızlıkların bir uzman tarafından doğru teşhisi, hekimin deneyimine ve benzer durumlar hakkındaki önceki bilgisine bağlıdır.
• Yapay zekâ kullanılarak bu sürecin geliştirilmesi son zamanlarda giderek daha popüler hale gelmiştir.
MEETCON-X 4. Uluslararası Bilimsel Araştırmalar Kongresi 2026

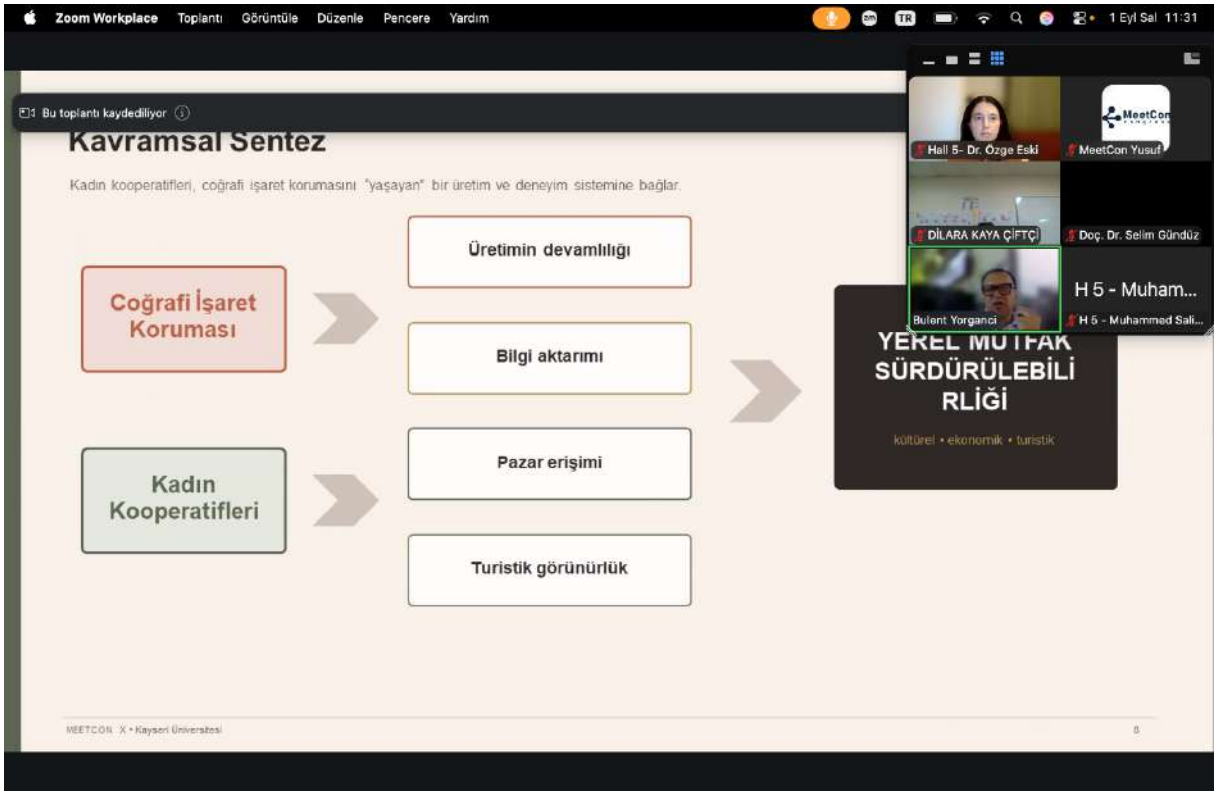

Zoom Workplace Toplantı Görüntüle Düzenle Pencere Yardım
1 Eyl Sal 12:01
Bu toplantı kaydediliyor
H-4 Ferdi DOĞAN
MeetCon Yusuf
h-4 Mikail
h-4 Melek Demir Perçin
Hall-4, Cana...
Hall-4, Canan Tastimur
O. narbonense (S)
O. narbonense (T)
O. yesiyurtense (S)
O. yesiyurtense (T)
O. yuarı (S)
Pentadekanoik (C15:0)
7.76
4.70
7.44
nd
14.05
Sıra Dışı Mar
Palmitik Asit Zirvesi
Palmitik (C16:0)
48.82
24.54
25.72
24.15
18.08
26.07
Oleik (C18:1)
13.18
7.38
8.22
10.31
Sıra Dışı Markerlar
nd
39.56
Linoleik (C18:2)
3.73
11.07
28.15
11.82
27.15
nd
Linoleik Asit Baskınlığı

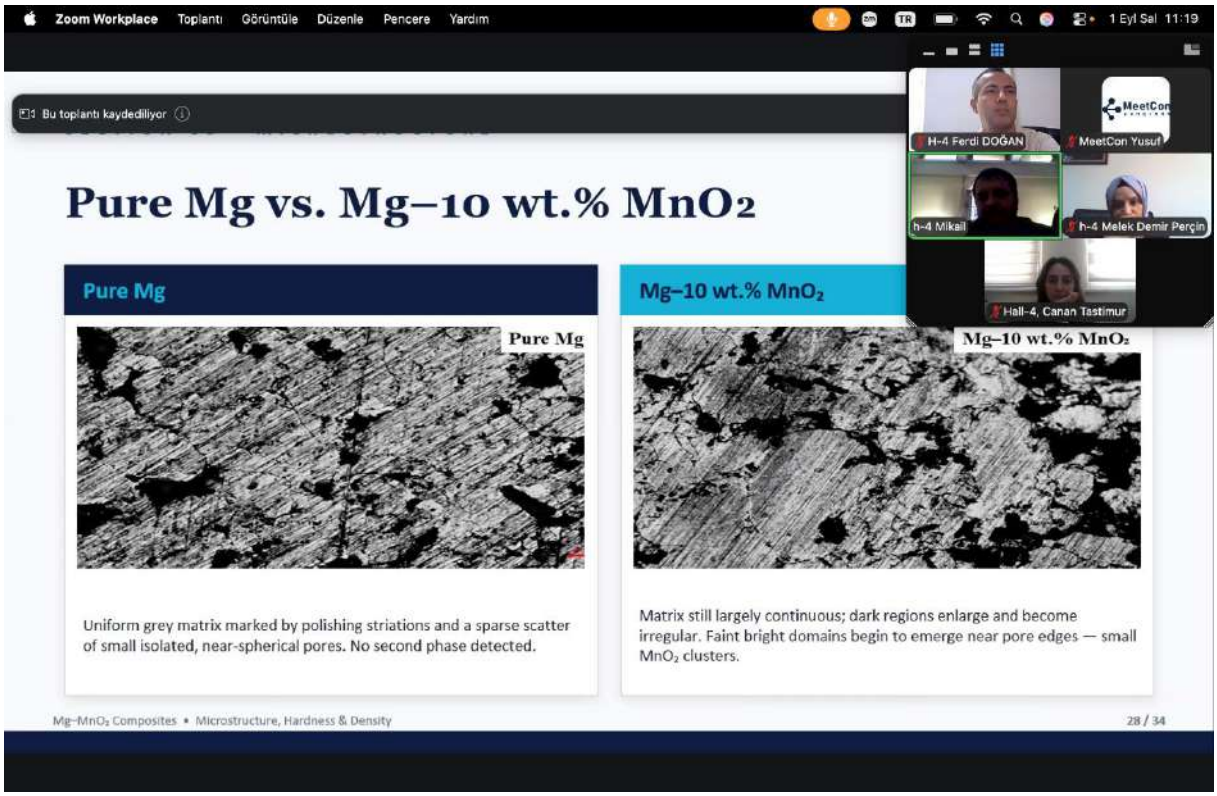

Zoom Workplace Toplantı Görüntüle Düzenle Pencere Yardım
1 Eyl Sal 12:00
Bu toplantı kaydediliyor
H 5 - Muhammed Salim...
MeetCon Yusuf
Hall 5- Dr. Özge Eski
DİLARA KAYA ÇİFTÇİ
Samsung SM...
Doç. Dr. Selim Gündüz
Samsung SM-A546E
H 5 - Muhammed Salim DANIŞ


Zoom Workplace Toplantı Görüntüle Düzenle Pencere Yardım
1 Eyl Sal 11:56
Gelecek Vizyonu: Akıllı MES
Nesnelerin İnterneti (IoT)
Yapay Zeka (AI)
Büyük Veri Analitiği (Big Data)
Akıllı MES
Geçmişten Geleceğe: "Ne oldu?" (Tanımlayıcı) aşamasından "Ne olacak?" (Kestirimci) aşamasına geçiş.
Adaptif Üretim: Değişen üretim koşullarına gerçek zamanlı ve otonom uyum sağlama.

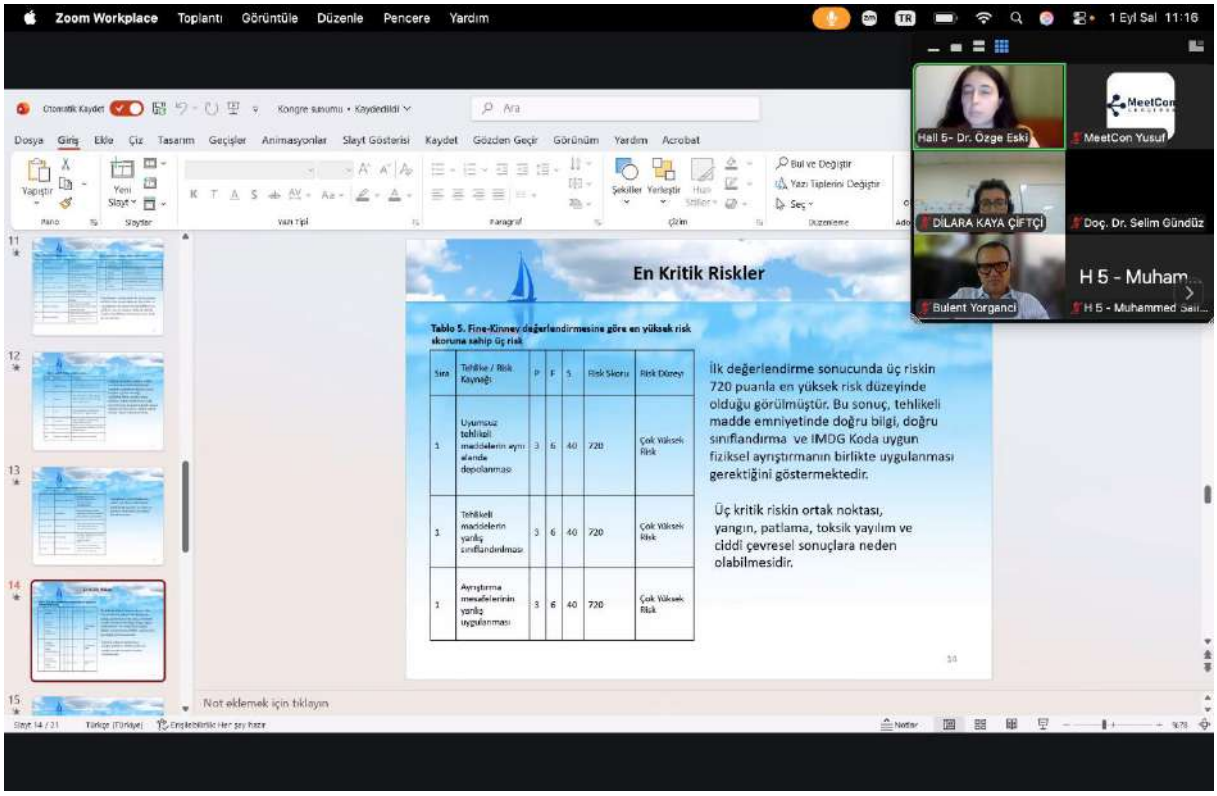

Zoom Workplace Toplantı Görüntüle Düzenle Pencere Yardım
1 Eyl Sal 11:44
DİLARA KAYA ÇİFTÇİ
MeetCon Yusuf
Doç. Dr. Selim Gündüz
Bulent Yorganci
Hall 5- Dr. Öz...
H 5 - Muham...
Hall 5- Dr. Özge Eski
H 5 - Muhammed Sali...
Makro Bağlam: Endüstri 4.0 ve Üre
Geleneksel Baskılar
Rekabet gücü; kalite, maliyet ve esnekliğin eşzamanlı yönetimine bağlıdır.
Kırılma Noktası
Üretim süreçlerinin karmaşıklaşması ve manuel takibin yetersiz kalması.
Endüstri 4.0 Paradigması
Siber-fiziksel sistemler, IoT ve eşzamanlı veri kullanımı. Karar alma süreçlerinin anlık veriye dayandırılması.

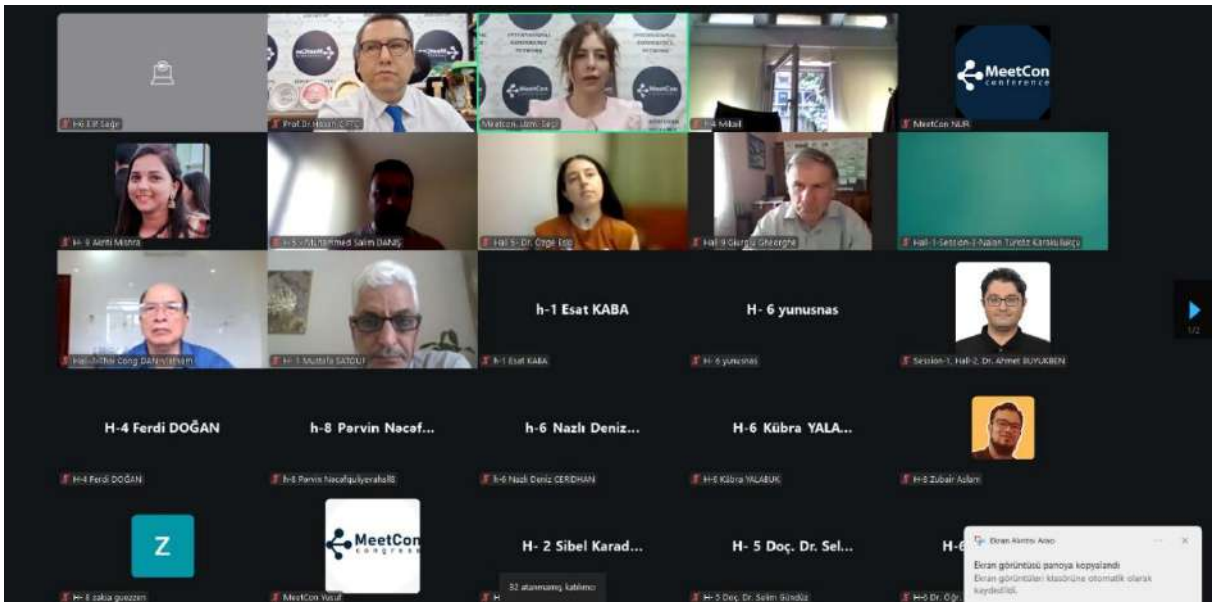

Zoom Workplace Toplantı Görüntüle Düzenle Pencere Yardım
1 Eyl Sal 11:40
Bu toplantı kaydediliyor
H-4 Ferdi DOĞAN
MeetCon Yusuf
h-4 Mikail
h-4 Melek Demir Perçin
Hall-4, Canan Tastimur
Prof.Dr.Hasan ÇİFTÇİ
01 Motivasyon ve Problem Tanımı
01 Mercan Resiflerinin Önemi
Okyanus tabanının yalnızca %0,1'ini kapsamasına rağmen deniz biyoçeşitliliğinin kritik bir bölümüne ev sahipliği yapar; turizm, balıkçılık ve ilaç sanayisine katkı sağlar.
02 Mercan Ağarması Krizi
Zooksantel alglerin stres nedeniyle dışarı atılmasıyla oluşur. 2016'da Büyük Set Resifi'nin %91'i tek bir ağarma olayında zarar gördü.
03 Manuel İzlemenin Yetersizliği
Geleneksel su altı izleme yöntemleri pahalı ve zaman alıcıdır; küresel ölçekte sürekli takip için bilgisayar destekli sistemlere ihtiyaç vardır.
04 Çalışmanın Amacı
9 derin öğrenme modeli (8 transfer + özgün CoralNet) ile sağlıklı/ağarmış mercanları otomatik sınıflandıran sistem geliştirmek ve karşılaştırmalı analiz sunmak.
1980'lerde 25-30 yılda bir → 2016'da 6 yılda bir kitlesel ağarma
Not ekleme için tıklayın





PROCEEDINGS BOOK


Zoom Workplace Toplantı Görüntüle Düzenle Pencere Yardım
1 Eyl Sal 11:16
Hall 5- Dr. Özge Eski
MeetCon Yusuf
DİLARA KAYA ÇİFTÇİ
Doç. Dr. Selim Gündüz
Bulent Yorganci
H 5 - Muham...
En Kritik Riskler
Tablo 5. Fine-Kinney değerlendirmesine göre en yüksek risk skoruna sahip üç risk
İlk değerlendirme sonucunda üç riskin 720 puanla en yüksek risk düzeyinde olduğu görülmüştür. Bu sonuç, tehlikeli madde emniyetinde doğru bilgi, doğru sınıflandırma ve IMDG Koda uygun fiziksel ayrıştırmanın birlikte uygulanması gerektiğini göstermektedir.
Üç kritik riskin ortak noktası, yangın, patlama, toksik yayılım ve ciddi çevresel sonuçlara neden olabilmesidir.
Not eklemek için tıklayın


MeetCon conference
h-1 Esat KABA
H- 6 yunusnas
H-4 Ferdi DOĞAN
h-8 Parvin Nəcəf...
h-6 Nazlı Deniz...
H-6 Kübra YALA...
MeetCon
H- 2 Sibel Karad...
H- 5 Doç. Dr. Sel...

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INTERNATIONAL CONFERENCE NETWORK

MEETCON - X
IV. INTERNATIONAL CONGRESS ON SCIENTIFIC RESEARCH

September 01-04, 2026 / Ankara, Türkiye

01.09.2026

CONGRESS PROGRAM

Meeting Id: 325 629 5864

Passcode: meetcon

Join Zoom Meeting

https://us06web.zoom.us/j/3256295864?pwd=cYbbqlXT67j0NliGNyeB4d7XTs1o6K.1&omn=86710175883



Önemli, Dikkatle Okuyunuz Lütfen

- Kongremizde Yazım Kurallarına uygun gönderilmiş ve bilim kurulundan geçen bildiriler için online (video konferans sistemi üzerinden) sunum imkanı sağlanmıştır.
- Online sunum yapabilmek için **https://zoom.us/join** sitesi üzerinden giriş yaparak "Meeting ID or Personal Link Name" yerine ID numarasını girerek oturuma katılabilirsiniz.
- Zoom uygulaması ücretsizdir ve hesap oluşturmaya gerek yoktur.
- Zoom uygulaması kaydolmadan kullanılabilir.
- Uygulama tablet, telefon ve PC'lerde çalışıyor.
- Her oturumdaki sunucular, sunum saatinden 5 dk öncesinde oturuma bağlanmış olmaları gerekmektedir.
- Tüm kongre katılımcıları canlı bağlanarak tüm oturumları dinleyebilir.
- Moderatör – oturumdaki sunum ve bilimsel tartışma (soru-cevap) kısmından sorumludur.

Dikkat Edilmesi Gerekenler- TEKNİK BİLGİLER

- Bilgisayarınızda mikrofon olduğuna ve çalıştığına emin olun.
- Zoom'da ekran paylaşma özelliğine kullanabilmelisiniz.
- Kabul edilen bildiri sahiplerinin mail adreslerine Zoom uygulamasında oluşturduğumuz oturuma ait ID numarası gönderilecektir.
- Katılım belgeleri kongre sonunda tarafınıza pdf olarak gönderilecektir
- Kongre programında yer ve saat değişikliği gibi talepler dikkate alınmayacaktır

IMPORTANT, PLEASE READ CAREFULLY

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- The Zoom application is free and no need to create an account.
- The Zoom application can be used without registration.
- The application works on tablets, phones and PCs.
- The participant must be connected to the session 5 minutes before the presentation time.
- All congress participants can connect live and listen to all sessions.
- Moderator is responsible for the presentation and scientific discussion (question-answer) section of the session.

Points to Take into Consideration - TECHNICAL INFORMATION

- Make sure your computer has a microphone and is working.
- You should be able to use screen sharing feature in Zoom.
- Attendance certificates will be sent to you as pdf at the end of the congress.
- Requests such as change of place and time will not be taken into consideration in the congress program.

Before you login to Zoom please indicate your name surname and HALL number: exp.Hall-1, Ali AY



01.09.2026 / ONLINE / SESSION-2 / HALL-4

Ankara Local Time: 11:00-13:00 September 1, 2026

Metting Id: 325 629 5864 Passcode: meetcon

HEAD OF SESSION: Assoc. Prof. Dr. Mikail ASLAN

Authors	Affiliation	Presentation Title
Mikail ASLAN	**MICROSTRUCTURAL CHARACTERIZATION, HARDNESS, AND DENSITY EVALUATION OF Mg-MnO2 COMPOSITES**	**Gaziantep University, Türkiye**
Mikail ASLAN	**THE MICROSTRUCTURE, HARDNESS AND DENSITY INVESTIGATION OF Mg COMPOSITES REINFORCED WITH Fe2O3**	**Gaziantep University, Türkiye**
Ferdi DOĞAN **Melek DEMİR PERÇİN**	**COMPARISON OF DEEP LEARNING MODELS FOR CORAL BLEACHING DETECTION AND THE CorefNet ARCHITECTURE**	**Adıyaman University, Türkiye**
Melek DEMİR PERÇİN	**BIOCHEMICAL AND CHEMOTAXONOMIC EVALUATION OF FATTY ACID PROFILES IN ORNITHOGALUM SPECIES**	**Adıyaman University, Türkiye**
Canan TASTIMUR	**AUTOMATED NAIL DISEASE CLASSIFICATION USING DEiT-TINY**	**Erzincan Binali Yildirim University, Türkiye**
Canan TASTIMUR	**SEMICONDUCTOR WAFER PATTERN RECOGNITION USING GHOSTNET: BALANCING ACCURACY AND PARAMETER EFFICIENCY**	**Erzincan Binali Yildirim University, Türkiye**

(All speakers required to be connected to the session 10 min before the session starts)
Moderator is responsible for ensuring the smooth running of the presentation, managing the group discussion and dynamics.



01.09.2026 / ONLINE / SESSION-2 / HALL-5

Ankara Local Time: 11:00-13:00 September 1, 2026

Metting Id: 325 629 5864 Passcode: meetcon

HEAD OF SESSION: Assoc. Prof. Dr. Selim GÜNDÜZ

Authors	Affiliation	Presentation Title
Özge ESKİ	RISK ASSESSMENT OF THE IMDG CODE DANGEROUS GOODS SEGREGATION PROCESS AT PORTS BY THE FINE-KINNEY METHOD	Zonguldak Bülent Ecevit University, Türkiye
Dilara KAYA ÇİFTÇİ	THE IMPACT OF MES AND MOM SYSTEMS ON PRODUCTION PERFORMANCE FROM AN INDUSTRY 4.0 PERSPECTIVE: AN APPLICATION IN AN AUTOMOTIVE PAINT SHOP LINE	Atatürk University, Türkiye
Abdulkadir KURTULAN Nuriye KARAKAYA Mehmet Emin BOZKURT	GİRİŞİMCİLİK VE YEŞİL İNOVASYON LİTERATÜRÜNÜN BİBLİYOMETRİK ANALİZİ	Karabük University, Türkiye
Abdulkadir KURTULAN Mehmet Emin BOZKURT Nuriye KARAKAYA	1989–2026 YILLARI ARASINDAKİ HİZMET PAZARLAMASI VE MÜŞTERİ MEMNUNİYETİNE DAİR AKADEMİK YAYINLARIN BİBLİYOMETRİK İNCELEMESİ	Karabük University, Türkiye
Muhammed Salim DANIŞ	THE TWO-WAY COURSE OF ACADEMIC MIGRATION IN TURKEY (1933–1950)	Afyon Kocatepe University, Türkiye
Bülent YORGANCI Reha KILIÇHAN	WOMEN'S COOPERATIVES IN THE SUSTAINABILITY OF LOCAL CUISINE: A CONCEPTUAL ASSESSMENT FROM THE PERSPECTIVE OF GEOGRAPHICAL INDICATIONS	Kayseri University, Türkiye
Selim GÜNDÜZ	DATA-DRIVEN DECISION MAKING IN AVIATION MANAGEMENT: FROM STATISTICS TO ARTIFICIAL INTELLIGENCE	Adana Alparslan Türkeş Science and Technology University, Türkiye
Selim GÜNDÜZ	QUANTITATIVE DECISION-MAKING METHODS IN AVIATION MANAGEMENT: STRATEGIC DECISIONS UNDER UNCERTAINTY	Adana Alparslan Türkeş Science and Technology University, Türkiye

(All speakers required to be connected to the session 10 min before the session starts)
Moderator is responsible for ensuring the smooth running of the presentation, managing the group discussion and dynamics.



01.09.2026 / ONLINE / SESSION-2 / HALL-6

Ankara Local Time: 11:00-13:00 September 1, 2026

Metting Id: 325 629 5864 Passcode: meetcon

HEAD OF SESSION: Nazlı Deniz CERIDHAN

Authors	Affiliation	Presentation Title
Pelin ZIVDIR YEŞİLYURT Kübra YALABUK	DIGITAL HEALTH LITERACY, TRUST IN ONLINE HEALTH INFORMATION, AND MENTAL WELL-BEING IN MENOPAUSE	Tarsus University, Türkiye
Kübra YALABUK Pelin ZIVDIR YEŞİLYURT	THE EFFECT OF DIGITAL TECHNOLOGY USE ON LONELINESS AND QUALITY OF LIFE IN OLDER ADULTS	Tarsus University, Türkiye
Elif SAĞIR Güzin BİLGİN BÜYÜKNACAR	EVALUATION OF MANDIBULAR TRABECULAR BONE STRUCTURE AND CONDYLE AND RAMUS MORPHOMETRY IN INDIVIDUALS WITH CLEFT LIP AND PALATE	Gaziantep University, Türkiye
Elif SAĞIR Güzin BİLGİN BÜYÜKNACAR Merve GÖYMEN Ayşegül GÜLEÇ	MULTIDISCIPLINARY ORTHODONTIC TREATMENT OF A PATIENT WITH GORLIN-GOLTZ SYNDROME ACCOMPANIED BY RECURRENT ODONTOGENIC KERATOCYSTS	Gaziantep University, Türkiye
Yunus NAS	AKUT ÜST SOLUNUM YOLU ENFEKSİYONU VE KAS-İSKELET SİSTEMİ YAKINMALARI OLAN ÇOCUKLARDA KREATİN KİNAZ YÜKSEKLİĞİNİN SIKLIĞI, ŞİDDETİ VE EŞ ZAMANLI LABORATUVAR BELİRTEÇLERİ: RETROSPEKTİF KOHORT ÇALIŞMASI	Hisar Hospital Intercontinental, Istanbul, Türkiye
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Mohammed Waheeb	TOWARDS SCIENTIFIC INDEPENDENCE AND REGIONAL INTEGRATION: A VISION FOR ESTABLISHING THE ARAB-ISLAMIC ARCHAEOBOTANICAL RESEARCH LABORATORY	The Hashemite University
Dr. Thai Cong Dan Thach Chanh Da Hoang Huynh Anh	FEMALE ADMINISTRATORS IN HIGHER EDUCATION AND SPECIALIZED CONTEXTS: NAVIGATING PROFESSIONALIZATION AND ADMINISTRATIVE COMPLEXITY	Can Tho University, Vietnam Little Beans Montessori Preschool
Dr. Thai Cong Dan Thach Chanh Da Hoang Huynh Anh	FEMALE ADMINISTRATORS IN SPECIALIZED EDUCATIONAL CONTEXTS: NAVIGATING PROFESSIONALIZATION AND INSTITUTIONAL CHALLENGES	Can Tho University, Vietnam Little Beans Montessori Preschool
Mohammed, Aliyu Suleiman Buhari Yahaya PhD Mohammed Isah Mohammed Stephen Jiya Mohammed Nasiru	UNIVERSAL HEALTH COVERAGE AND PRIMARY HEALTHCARE STRENGTHENING: PATHWAYS TO EQUITABLE HEALTH SYSTEMS	Umaru Sanda Ahmadu College of Education Minna, Niger State
Makwe, Emmanuel Uzoma	INTERNATIONAL TRADE AND THE PERFORMANCE OF THE NIGERIAN ECONOMY	University Of Port Harcourt
Umar Baba Shaaba	BLOCKCHAIN TECHNOLOGY AND THE FUTURE OF FINANCIAL REPORTING: OPPORTUNITIES AND CHALLENGES FOR NIGERIAN BUSINESSES	Ahman Pategi University, Kwara State, Nigeria
Umar Baba Shaaba	BIG DATA ANALYTICS AND MODERN ACCOUNTING PRACTICES: IMPLICATIONS FOR THE ACCOUNTING PROFESSION IN NIGERIA	Ahman Pategi University, Kwara State, Nigeria
Karim MAHAMANE KARIMOU,Oumarou ADAMAOU IDÉ	THE CASE AGAINST HYPOCRISY IN THE COMMUNITY: EXPLORATION OF JHONEL'S 1000 POEMS	Abdou Moumouni University—UAM—(Niamey/Niger) Djibo Hamani University of Tahoua — UDH/T
Dr. Raf Raf Shakil Ansari	WHO IS THE MONSTER? POSTHUMAN OTHERNESS AND THE CRISIS OF HUMAN EXCEPTIONALISM IN I AM LEGEND	Sharda University, India

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HEAD OF SESSION: PhD Gulnar Atakishiyeva

Authors	Affiliation	Presentation Title
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Parvin Najafguliyeva Arzu Rustamova	METABOLIC SYNDROME AND MODERN THERAPEUTIC AND SURGICAL APPROACHES TO ITS MANAGEMENT	Azerbaijan Medical University, Baku, Azerbaijan
Said Kerraj, Mohamed elmamouni, Mohamed Moussaoui	ARENE LIGAND ENGINEERING IN CHROMIUM HALF-SANDWICH COMPLEXES TOWARD ENHANCED DYE-SENSITIZED SOLAR CELL PERFORMANCE	Hassan II University of Casablanca, Morocco Mohammed VI Polytechnic University, Morocco
Waliyat Folasade FATAI, Tajudeen Kolawole BELLO	PRODUCTION OF COMPOSITE BRIQUETTES FROM CHARRED AND UNCHARRED COCONUT SHELL FILLED WASTE PAPER AND STARCH BINDER	Ahmadu Bello University, Zaria, Nigeria
Hajar EL GANICH Omar Ben Lenda Omar EL RHAZOUANI Elmadani SAAD	MAGNETIC BEHAVIOR OF HIPERCO 50-TYPE SOFT MAGNETIC ALLOY: A MONTE CARLO SIMULATION	Hassan First University of Settat, Morocco
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Assil CHAOUI	ENHANCING THERMAL PERFORMANCE IN INDUSTRIAL COOLING SYSTEMS VIA ELLIPTICAL TUBES AND ADVANCED BAFFLE DESIGNS	University Larbi Ben M'hidi of Oum El Bouaghi, Algeria
Zakia GUEZZEN, Zakia HAMMOU, Zouaoui SEREIR, Aicha BOUSSOUFI, Lahouaria ERROUANE	EXPERIMENTAL INVESTIGATION OF VIBRATION DAMPING IN ALFA FIBER-REINFORCED CYLINDRICAL SHALLOW SHELLS	University of Science and Technology of Oran, Oran, Algeria
Muhammad Faisal	ARTIFICIAL INTELLIGENCE-POWERED DIGITAL TWINS FOR SMART ENTERPRISES ENHANCING OPERATIONAL INTELLIGENCE THROUGH REAL-TIME VIRTUAL MODELING	Joint Director (AICU) at Ministry of IT & Telecommunication, Pakistan

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HEAD OF SESSION: Major Gheorghe GIURGIU

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Dalap, S. L., Ibrahim, M., Shehu, B., Muhammad, U. H., Muhammed, Y.	COMPARATIVE ASSESSMENT OF EXTENSION AND ADVISORY SERVICE NEEDS OF CEREAL CROP FARMERS IN NASARAWA AND PLATEAU STATES, NIGERIA	Federal University of Technology, Minna, Niger State, Nigeria
Meriem TAIER, Samra BENKACEM, Walid BOULTIF	PREDICTION OF CHLORINE DOSE IN A DRINKING WATER TREATMENT PLANT USING ARTIFICIAL NEURAL NETWORKS: APPLICATION TO BENI ZID STATION, SKIKDA, ALGERIA	University of Skikda, Algeria
Muhammed, Y. Onuoha, E. I. Ajayi, O. J.	EFFECTS OF AGRICULTURAL EXTENSION SERVICE DELIVERY ON NUTRITIONAL STATUS OF STAPLE FOOD CROP FARMERS IN BENUE STATE, NIGERIA	Federal University of Technology, Minna, Niger State, Nigeria
Fatemeh Molaei Tavani Masoumeh Bagheri-Nesami Fazlollah Ahmadi	FROM INFORMATION FRAGMENTS TO KNOWLEDGE COHERENCE: RETHINKING NURSING STUDENTS' LEARNING IN THE ERA OF GENERATIVE AI	Mazandaran University of Medical Sciences, Sari, Iran Tarbiat Modares University, Tehran, Iran
Major Gheorghe GIURGIU Prof. dr. med. Manole COJOCARU	WHAT WE KNOW ABOUT PSORIASIS SO FAR?	Deniplant-Aide Sante Medical Center, Romania Academy of Romanian Scientists Titu Maiorescu University, Romania

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MICROSTRUCTURAL CHARACTERIZATION, HARDNESS, AND DENSITY EVALUATION OF Mg-MnO_2 COMPOSITES

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ABSTRACT

The objective of this experiment is to study the influence of the addition of MnO2 on the density, hardness, and microstructure of magnesium alloys synthesized through powder metallurgy technique. Four samples are prepared, including one sample that contains only magnesium matrix and three other samples that contain 10%, 30%, and 50% of MnO2 respectively. The powder blends were homogenised by magnetic stirring, uniaxially cold-pressed at 300 MPa, and then sintered. The bulk density was determined by the Archimedes method, the microhardness was measured using a Vickers indenter, and microstructural examination was conducted with an optical microscope. The unreinforced Mg sample had a density of 1.67 g/cm3 and a hardness of 35.2 HV. The hardness was increased greatly by the addition of MnO2. It reached 43.0 HV at 10 wt.% and increased to 43.6 HV at 30 wt.%, which is about 24% higher than the baseline value. Along with the hardness, the bulk density also increased and at this composition, the value of 1.79 g/cm3 was achieved. However, the density decreased slightly at 50 wt.% (42.4 HV). Residual porosity was compared to the rule-of-mixtures prediction and found to have risen from less than 4% in the pure Mg sample to approximately 30% for 50 wt.% MnO2. This change was also confirmed by optical micrographs, which showed the gradual transition from a near-continuous Mg matrix to the large MnO2 clusters with an interconnected pore network in between. The 30 wt.% composition gave the most favourable compromise between strengthening, retained matrix continuity and bulk density and is therefore identified as the practical optimum under the processing conditions used in this work.

Keywords: Magnesium matrix composite, Manganese dioxide, Powder metallurgy, Vickers hardness, Bulk density, Optical microstructure.

INTRODUCTION

Magnesium (Mg) is the lightest structural metal with a density of approximately 1.74 g/cm^3, which is about two thirds the density of aluminium and one quarter that of steel (Mordike & Ebert, 2001) . Owing to their excellent castability, high damping capacity, good machinability, and impressive specific strength, Mg and its alloys have gained significant attention in diverse applications of engineering such as automobile, aerospace, electronics, and biomedical fields (Luo, 2002; "Magnesium Alloys," 2011). The car industry, in particular, is using more and more Mg parts in their vehicles to reduce the weight and, as a result, the fuel consumption and the CO_2 emissions. This trend is in line with the tightening of the environmental regulations. The aerospace industry, likewise, can utilize Mg alloys for the low density to achieve the right value of the strength to the weight that is very crucial for the structural parts of the planes and for the portable machines (Tur & Öztürk, 2024). As regards biomedical applications, the natural ability of Mg to undergo bio-degradation has motivated numerous studies on the development of a biodegradable implant using Mg due to the similarity of the elastic modulus of Mg of around ~45 GPa to the elastic modulus of human cortical bone, rather than titanium and stainless steel (Zheng, Gu, Xi, & Chai, 2010).

Yet, even considering all the above-listed advantages, the widespread use of magnesium and its alloys also face several limitations caused by their specific properties. First of all, since magnesium is the material of the hexagonal closed-packed type (HCP), its number of active slip planes is quite restricted,

making magnesium brittle and non-formable. Second, pure magnesium is characterized by lower hardness, wear resistance, and modulus of elasticity compared to other lightweight metals, including aluminum (Casati & Vedani, 2014). Lastly, magnesium has low corrosion resistance because of its instability in a corrosive atmosphere, when the formation of porous oxide film on magnesium surface makes this metal more susceptible to galvanic corrosion and pitting. That is why a lot of attention is paid to improvement of magnesium-based materials' physical and mechanical properties.

One of the most promising ways to surpass the limitations inherent to monolithic magnesium is the metal matrix composites (MMCs). The incorporation of a hard and thermally stable reinforcement phase into the Mg matrix allows for simultaneous improvements in hardness, elastic modulus, yield strength, ultimate tensile strength and wear resistance while keeping the low density characteristic of the matrix material or even improving it (M. Paramsothy, Hassan, Srikanth, & Gupta, 2010; Wang et al., 2014). The composite approach thus provides a unique way to engineer material properties that are not accessible through alloying alone. During the last two decades, a wide variety of reinforcement materials have been investigated in Mg-based MMCs, such as carbides (SiC, TiC), nitrides (AlN, Si3N4), oxides (Al2O3, TiO2, ZnO) and borides (TiB2). With respect to that, ceramic oxides are particularly remarkable due to their superior hardness, chemical stability at high temperatures, economical nature, and affinity for Mg alloys (Zhang & Chen, 2006).

It is possible to highlight a number of features of the MMCs containing Mg that strongly rely not only on the material itself and the volume fraction of the reinforcing particles used, but also on the selected method for their preparation. The methods widely used for preparing the MMCs include stir casting, infiltration, disintegrated melt deposition (DMD), and powder metallurgy (PM). It seems that the PM technique might be among the most suitable ones to produce uniform material with a fine microstructure. As a result, it becomes necessary to mix and densify powders of the matrix and reinforcing materials and then carry out the sintering of the material obtained. Temperature, pressure, and time are among the key parameters of the sintering process, especially when performed under a protective gas atmosphere (Tun & Gupta, 2007).

The manganese oxide (MnO_2) is one of the transition metal oxides which has been gaining significant importance due to its prospective applications as a reinforcement in light metal matrix composites. Being in the most thermodynamically stable form (β-MnO_2, pyrolusite structure), MnO2 displays a relatively high Vickers hardness of 5–7 GPa (Callister Jr & Rethwisch, 2020), Young's modulus value around 60–80 GPa (Murillo & Navarrete, 2021), good thermal stability, and electrochemical properties (Djurfors, Broughton, Brett, & Ivey, 2005). Besides being successfully utilized as an electrode material in battery technology and supercapacitors, MnO2 has also been identified as a multifunctional ceramic phase with a promising possibility to reinforce metallic matrixes (Devaraj & Munichandraiah, 2008). Being incorporated into the Mg-based matrix under thermal treatment conditions, MnO2 particles can participate in thermally induced interfacial reactions with the matrix. The reaction consists of the decomposition of MnO2 in the process, $MnO_2 \rightarrow Mn_2O_3 \rightarrow Mn_3O_4 \rightarrow MnO$, at temperatures above ca. 530 °C, with the evolved oxygen further reacting with magnesium to form a thin interphase of MgO around MnO2 particles in a Mg matrix (Preiss, Meyer, & Olschewski, 1998). Such in-situ formed MgO interlayers are known to strengthen the interfacial bond, suppress interfacial debonding under loading, and improve load-transfer efficiency from the matrix to the reinforcement (Lloyd, 1994). Moreover, dissolved Mn ions are well established to improve the corrosion resistance of Mg alloys by scavenging harmful Fe impurities and lowering the Fe/Mn ratio below the tolerance limit, thereby reducing the density of cathodic sites (Song & Atrens, 1999).

The complete characterization of Mg-MnO_2 composites entails the application of various analyses in combination. The optical microscope (OM) is necessary for revealing the mesoscopic microstructural properties, such as reinforcement homogeneity, matrix microstructure, grain boundaries, clustering tendency, as well as the probability of pore existence or other problems (Vander Voort, 1999). The quantitative metallographic evaluation by the means of optical microscope gives statistical information on the dimensions and spatial distribution of particles affecting the mechanical properties of the composite [8]. The most common methods for hardness testing include the Vickers (HV) or Brinell (HB) tests, providing a fast and simple method for the estimation of mechanical property improvement

by the reinforcement material (Handbook, 2000). It should be noted that hardness is strongly dependent on such factors as grain size, dislocation density, solid solution strengthening, and composite strengthening [6]. Density measurement by the Archimedes' principle helps to determine the degree of sintering, since the existence of pores leading to low bulk density relative to the theoretical value indicates poor processing and weak structure (Handbook, 2000). The ratio of measured density to theoretical density, expressed as relative density, is widely employed as a benchmark for assessing the effectiveness of the PM consolidation process.

Even though numerous research studies have been conducted to investigate the reinforcement of Mg composites using conventional ceramic materials such as SiC, Al_2O_3, and TiO2, there seems to be a lack of literature regarding the use of MnO2 as a reinforcing agent in magnesium-based metallic matrix composites. Hassan and Gupta found that Mg alloys containing nano-Al2O3 reinforcements showed considerable increase in hardness and tensile behavior, while maintaining relatively high levels of ductility. In a similar study, Wong and Gupta managed to show that nano-SiC was capable of improving the tensile strength and ductility of magnesium-based composites due to grain refinement and Orowan strengthening (E Wong & Gupta, 2006). According to Paramsothy et al., reinforcement of ZK60A Mg alloys with TiC nanoparticles could considerably enhance yield strength and ultimate tensile strength without having a negative effect on density (Muralidharan Paramsothy, Chan, Kwok, & Gupta, 2011). However, considering the physicochemical properties of MnO_2, including chemical reaction within interfaces, effects of Mn dissolution on corrosion properties, as well as high hardness, research in this area would certainly be scientifically interesting.

For the present research, it is intended to carry out synthesis of Mg matrix composites strengthened by MnO_2 through powder metallurgy method. It would be attempted to carry out analysis of the microstructural, mechanical, and physical properties of these composites. Evaluation of distribution of MnO_2 particles in Mg matrix, as well as study of changes in grain structure with variation in percentage of reinforcement would be undertaken through optical microscopy technique. Study of hardness of the composites would be conducted to evaluate the effect of reinforcement on strengthening of these composites. Testing for density of the samples based on Archimedes' principle would be carried out to find out the degree of consolidation and densities of the composite samples synthesized.

METHODOLOGY

Raw Materials

Magnesium (Mg) powder and manganese dioxide (MnO2) were procured from Nanografi and ZAG Chemistry, respectively. All materials were used as received without further purification.

Composite Fabrication

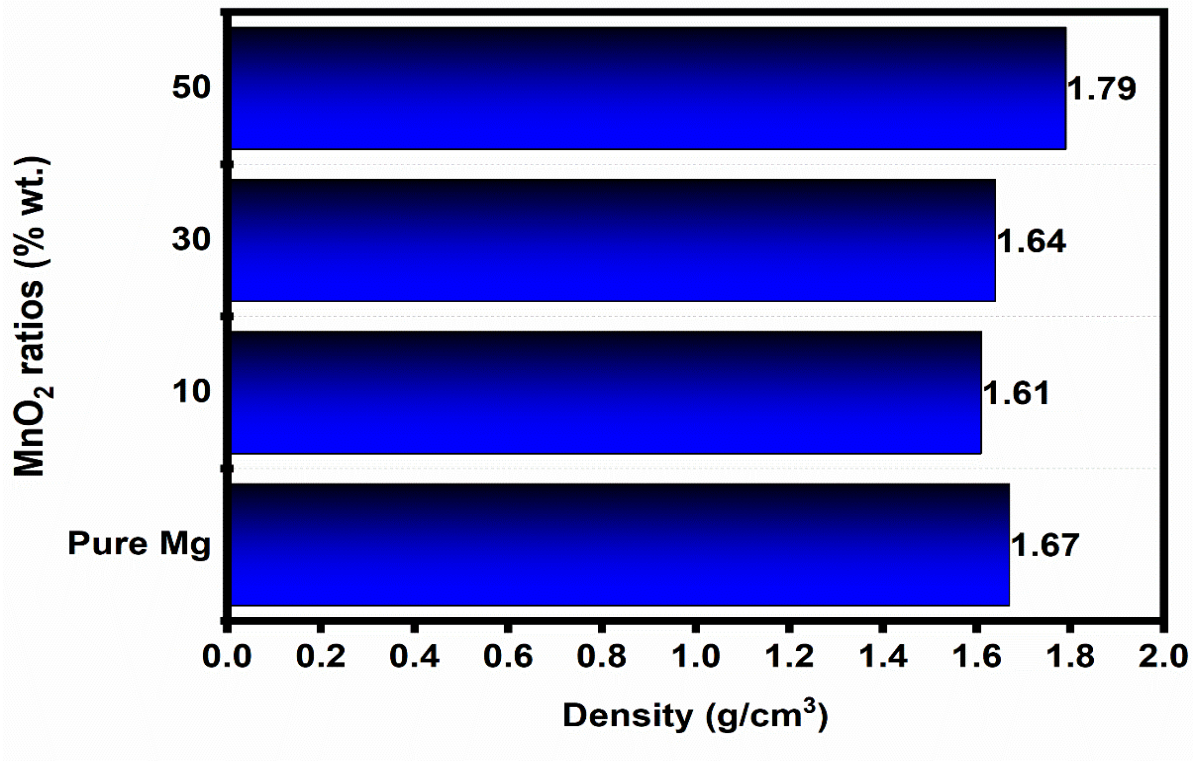
Composite materials of Mg and MnO2 were synthesized through powder metallurgy process. For each mixture, the total mass of 7 grams of powders was taken while the amount of MnO2 was varied as 10, 30, and 50 wt.% to study the effect of reinforcement percentage on the material. The amount of Mg powders would compensate the balance of each composition. All the required powders were transferred to a beaker where they were mixed by means of a magnetic stirrer working at 800 rpm for 30 minutes. Thereafter, the powder compositions were uniaxially pressed under the pressure of 300 MPa in a cylindrical die made of steel.

RESULT AND DISCUSSION

Density Variation with MnO_2 Reinforcement Content

Figure 1 presents the bulk density values obtained from the four sintered samples examined in this study. The unreinforced magnesium reference reached a density of 1.67 g/cm^3, which corresponds to roughly 96.1% of the theoretical density of pure Mg (≈1.738 g/cm^3). But for 10 wt% of MnO2, there was no corresponding rise in density based on the mixture formula; rather, it decreased to 1.61 g/cm3. For 30 wt%, it rose to 1.64 g/cm3, while for 50 wt%, it finally exceeded the density of the baseline at 1.79 g/cm3.

Figure 1. Densitiy values of the given composites



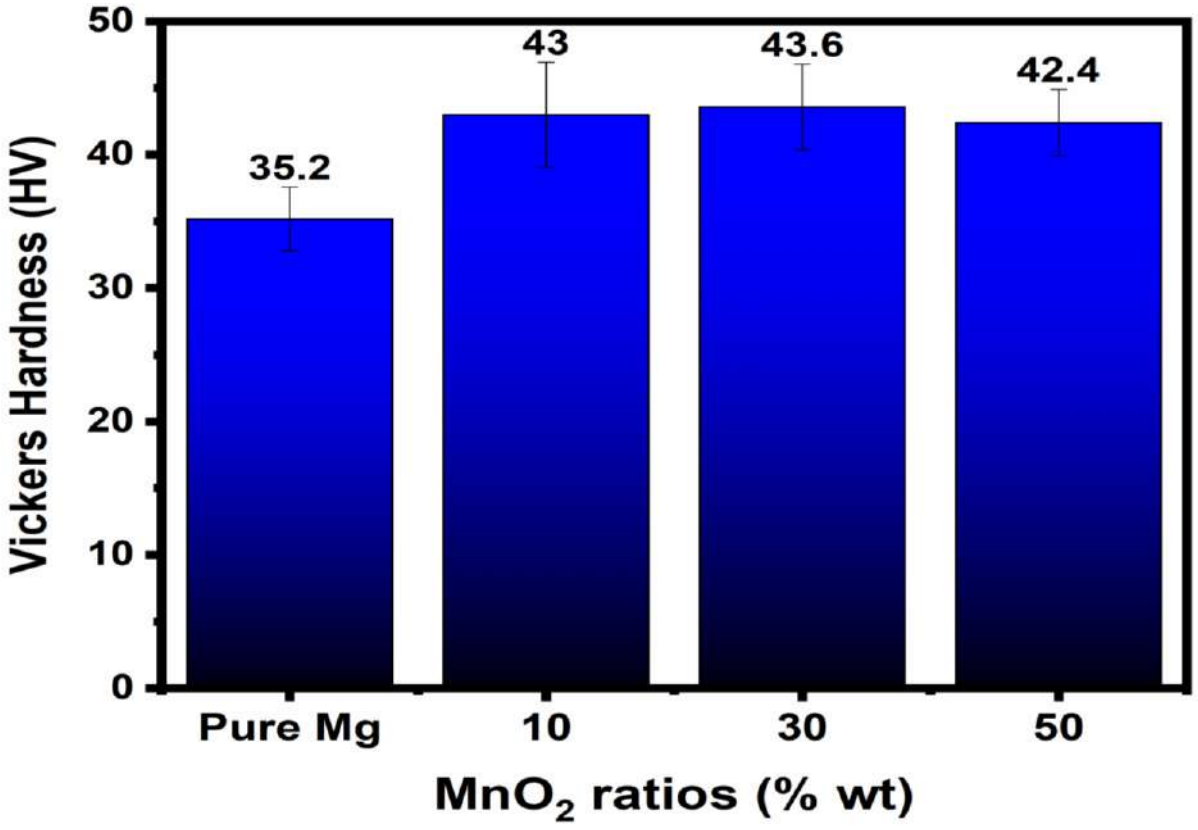
The non-linear response is because of the relationship between the two factors responsible. The first one, which is MnO_2, has an extremely high inherent density (about 5.03 g/cm3). On the other hand, the density of magnesium is quite low. Using the Rule of Mixtures method, the theoretical densities for the composites containing 10%, 30% and 50% weight percent of reinforcement are found to be 1.86 g/cm3, 2.16 g/cm3, and 2.58 g/cm3, respectively. In comparison with the theoretical values, we obtain the relative densities of 86.6%, 75.9% and 69.3%. The heavier ceramic phase therefore pulls the apparent density upward while the developing pore network drags it down. At 10 wt.% the porosity penalty wins; at 50 wt.% the mass of MnO_2 finally overtakes it. Comparable porosity windows of 24–29 vol.% have been documented in conventional pressed-and-sintered magnesium prepared under controlled argon atmospheres (Čapek & Vojtěch, 2014), which sits in the same range as the 30 and 50 wt.% specimens analysed here.

Reinforcement-induced loss of relative density is a recurring theme in the magnesium-composite literature. Hot consolidation of Mg powders mixed with MgO and Al_2O_3 at 600 MPa, for example, produced a clear inverse relationship between reinforcement fraction and relative density, with the lowest density obtained at the highest ceramic loading (Rahmani et al., 2023). The same trend is observed in the present Mg–MnO_2 system, suggesting that the limited matrix flow around large ceramic clusters is the dominant densification obstacle once the reinforcement content moves beyond a few weight percent.

Vickers Hardness Response

Figure 2 summarises the Vickers microhardness data measured on the same set of specimens. The pure Mg exhibited a hardness of 35.2 HV with a slight deviation in the band. This hardness level falls within the typical hardness levels achieved in the case of sintered magnesium that does not have any alloying agents. A hardness increase of about 22% was observed when 10 wt.% of MnO2 was added to yield a hardness of 43.0 HV. At 50 wt.% the curve turned over and the hardness fell back to 42.4 HV.

Figure 2. Microhardness values of the given composites



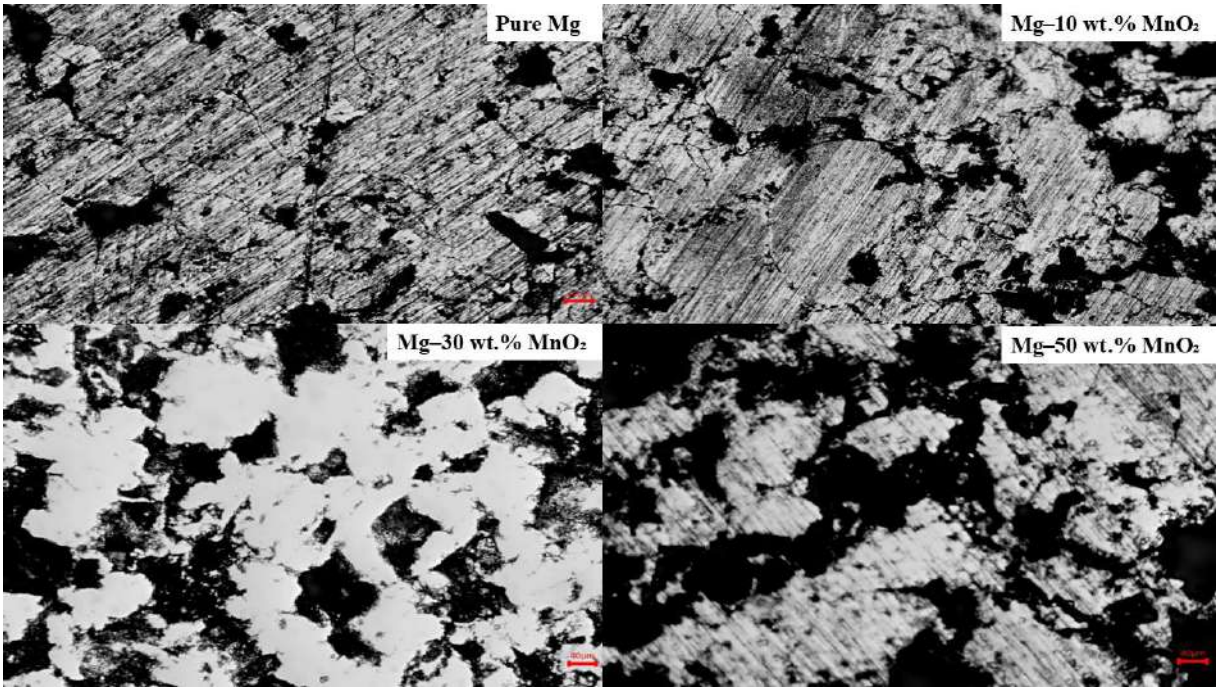
The strengthening observed up to 30 wt.% can be traced to the classical mechanisms active in particulate metal-matrix composites: load transfer from the softer Mg matrix to the rigid MnO_2 particles, accumulation of dislocations around the second phase, and the generation of geometrically necessary dislocations driven by the substantial thermal-expansion mismatch between magnesium ($\approx 26 \times 10^{-6}$ K^{-1}) and the oxide reinforcement during cooling from the sintering temperature. Hassan and Gupta showed, for instance, that the blend–press–sinter route allows nano-Al_2O_3 additions to magnesium to simultaneously raise hardness, yield strength, ultimate tensile strength and ductility provided that the particles remain reasonably well dispersed (Hassan & Gupta, 2005). The 10 wt.% jump observed here is consistent with that mechanism: even a modest amount of well-bonded MnO_2 already produces most of the achievable strengthening.

The plateau between 30 and 50 wt.% and the small reversal at the highest loading point to the gradual onset of detrimental effects. In the case of hot extruded magnesium matrix containing 3 vol.% of laser synthesized SiC nanoparticles, the results indicate that in most cases ball milling before consolidation is required to prevent agglomerate formation since otherwise, the presence of the agglomerates will very quickly impair the process of load transfer (Ferkel & Mordike, 2001). With the increasing of the percentage of reinforcing material, the amount of matrix material will become smaller. The dislocations won't move freely through the particles any more, and the rise in the porosity of Figure 1 impacts the ability of the matrix to withstand the load transfer.

Optical Microstructural Observations

Some of the optical microscopic pictures of the specimens are shown in Figure 3. The magnesium specimen (left upper part) shows fairly uniform grey portion that has grinding line along with few spots here and there, indicating existence of spherical pores. Second phase does not exist in the sample, which is consistent with unreinforced sintered magnesium. But for the Mg-10 wt.%MnO2 specimen (right upper part), the metallic portion remains fairly intact, but with few dark spots and slightly bright areas around the edges of porosity. These bright features are interpreted as MnO_2 particles and small clusters embedded in the Mg matrix.

Figure 3. Optic microscope images of the given composites



The microstructural evolution becomes far more pronounced at 30 wt.% (lower left). Large, brightly reflecting domains now dominate the field of view, separated by extensive black regions. The bright phase is the MnO_2 reinforcement, present in such quantity that it forms continuous clusters rather than isolated particles. The black areas correspond to open porosity where the magnesium failed to fully wet and densify around the oxide aggregates. This dual-phase morphology is in line with the bimodal-distribution arguments made for hybrid Mg–(Ti + n-Al_2O_3) composites, where uniformly dispersed reinforcement is a prerequisite for the expected mechanical gains and where ball milling is needed to suppress clustering (Sankaranarayanan, Jayalakshmi, & Gupta, 2011). In the present material, the very large reinforcement load makes such uniformity difficult to achieve and explains both the wider hardness scatter and the depressed relative density at this composition.

The Mg–50 wt.% MnO_2 specimen (lower right) again exhibits two distinct contrast regions, but the arrangement is more fragmented. The reinforcement domains are still large yet more dispersed, and the intervening Mg matrix retains visible polishing lines indicating crystalline metal. Similar bright-cluster / dark-pore morphologies have been reported for Mg matrices containing 0.3 wt.% carbon nanotubes, where the porosity level rose sharply once reinforcement clustering began (Goh, Wei, Lee, & Gupta, 2006). The micrograph here captures essentially the same phenomenon at a much higher loading: the ceramic phase has formed an interconnected skeleton, but the matrix between the ceramic patches is no longer continuous enough to support efficient load transfer, which accounts for the slight drop in hardness at 50 wt.% despite the favourable density value.

Comparative Discussion

The interaction of these three parameters points out an observable tendency connecting the material's properties to its microstructure in the case of Mg-MnO2 composite. Hardness exhibits a dramatic rise in the interval 0-10 wt.% (35.2-43.0 HV) and continues growing slowly up to 30 wt.% (43.6 HV), while dropping slightly at 50 wt.% (42.4 HV). On the other hand, the graph of density is characterized by a more complex pattern; it falls down at 10 wt.%, rises up to 30 wt.%, and surpasses the graph of Mg at 50 wt.%. The possible explanation of this discrepancy is in the scale of probing for each particular property: the effect of reinforcement on hardness is significant, while the bulk density is determined by the overall structure of pores in the ceramic-containing composites due to impossibility of the formation of the sintering neck between Mg particles. It should be pointed out that a similar situation was detected during consolidation of Mg by microwave-assisted rapid sintering, containing submicron reinforcements of Al_2O_3 (Wong, Karthik, & Gupta, 2005).

Combining all three plots, the composition 30 wt.% is determined as practical optimal in the given concentration interval. It provides the highest average hardness (43.6 HV, i.e. about 24% higher than that of pure Mg), keeping bulk density quite close to the benchmark (1.64 g/cm3), along with microstructure featuring the highest level of reinforcement-matrix interaction. Further increase of the amount of MnO_2 to 50 wt.% is not beneficial from the mechanical viewpoint, since it leads to creation of the microstructure featuring broken two-phase structure that, while being denser, performs worse in terms of mechanical properties. It should be noted that the observed trend of achieving an intermediate optimum followed by a decline has been recorded for a number of Mg-based composites, e.g. hybrid composites containing micro- and nano-Al_2O_3 reinforcements, produced using the Mg-3Zn-0.7Zr-1Cu matrix and featuring the highest hardness attained at the intermediate sintering temperature (Suneesh & Sivapragash, 2021).

CONCLUSION

Pure magnesium and Mg-MnO_2 composite alloys consisting of 10, 30 and 50 wt.% MnO_2 reinforcements were fabricated by powder metallurgy technique and characterized based on density measurement via Archimedes principle, hardness measurement using Vickers hardness tester and microscopic examination. Some findings that may be obtained include the following:

(1) The Vickers hardness of pure Mg was 35.2 HV, while 10 wt.% and 30 wt.% MnO2 reinforcements increased this value to 43.0 HV and 43.6 HV, respectively, indicating an increment in hardness of about 24%. Factors affecting hardness include transfer of load to the rigid oxide particles, pileup of dislocation at matrix/reinforcement interface, and creation of dislocations because of different coefficients of thermal expansion of two materials.

(2) It was seen that density was not a function of linear increase in reinforcement concentrations. Density of pure Mg was determined to be 1.67 g/cm3; however, density of 10 wt.% Mg and 30 wt.% Mg was smaller than this pure Mg density at 1.61 and 1.64 g/cm3, respectively. On the other hand, density of 50 wt.% alloy was larger than pure Mg density at 1.79 g/cm3. Relative densities decreased from 96% in pure Mg to 69% in 50 wt.% MnO2.

(3) Microstructural evolution was analyzed by means of optical microphotographs and explained the changes in properties. A pure magnesium sample showed rather uniform microstructure without pores. For the 10 wt.% sample, one could see a predominantly continuous microstructure and MnO2 aggregates located at the pore edges. The samples containing more than 30 wt.% MnO2 showed large portions of microstructure covered with darkness as the result of porosity; MnO2 showed its presence in bright spots.

(4) Considering such parameters as hardness, density, and microstructure features, it should be mentioned that the best composition is 30 wt.% of MnO2. This composition shows the highest hardness value, good enough continuity of microstructure for mechanical load transfer and appropriate density similar to the reference sample.

(5) Hardness inversion in the case of 50 wt.% of MnO2 indicates the upper limit of adding this material, requiring additional investigations with paying attention to the method of high-energy ball milling for

preventing agglomeration of MnO2 particles, as well as additional manufacturing techniques such as hot pressing and extrusion of samples.

Taken together, these findings support the concept that MnO2 can be an effective strengthening particle in magnesium, provided its content in the alloy remains reasonably low. This research contributes significantly to the existing knowledge base on this specific system and stands out as a very useful benchmark for further development of Mg alloys reinforced by oxides.

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THE MICROSTRUCTURE, HARDNESS AND DENSITY INVESTIGATION OF Mg COMPOSITES REINFORCED WITH Fe_2O_3

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ABSTRACT

The Fe_2O_3 reinforced magnesium (Mg) metal matrix composites have been successfully fabricated by powder metallurgy in the present work to study the influence of iron oxide reinforcement on microstructure, density and hardness behavior. The Mg matrix was reinforced with Fe_2O_3 at 5, 10 and 15 wt.%. The powder mixtures were cold-compacted at 300 MPa and characterized by optical microscopy (OM), Archimedes density and Vickers microhardness tests. The results showed that the physical and mechanical properties of the composites were greatly affected with the addition of reinforcement content. Pure Mg had a density of 1.67 g/cm^3 and a hardness of 35.2 HV. The density decreased to 1.58 g/cm3 with the addition of 5 wt% Fe_2O_3 due to poor particle dispersion and increased residual porosity. However, with an increase in the reinforcement content to 10 and 15 wt.% the density increased to 1.69 and 1.70 g/cm^3 respectively indicating enhanced densification and improved matrix-reinforcement bonding. Despite the incorporation of high-density Fe_2O_3 particles, all composites maintained low densities below 2 g/cm³ and thus retained their lightweight nature. The hardness values increased progressively with increasing Fe_2O_3 content, obtaining 42.2 HV and 45.8 HV for 10 and 15 wt.% reinforcement, respectively. The improvement was attributed to load transfer strengthening, grain boundary pinning and reduced porosity at higher levels of reinforcement. Optical microscopy confirmed a more homogeneous reinforcement distribution and less pore formation at higher Fe_2O_3 concentrations. Overall, the study reveals that Fe_2O_3 is an effective reinforcement for improving the hardness and densification behavior of Mg-based composites, while maintaining low density for lightweight engineering applications. Overall, the study reveals that Fe_2O_3 is an effective reinforcement for improving the hardness and densification behavior of Mg-based composites, while maintaining low density for lightweight engineering applications.

Keywords: Fe_2O_3, Mg, Hardness, Density, Optical Analyses

INTRODUCTION

Magnesium (Mg) is one of the materials that has become very popular for use in construction materials in this century (Polmear, StJohn, Nie, & Qian, 2017). Mg weighs only 1.74 g/cm3, which is around 35% lighter than aluminium and 80% lighter than steel. Besides, it has an entirely different set of qualities, such as a low weight with a moderate strength and good machining and casting, which in combination result in a material most suitable for engineering applications in which weight is a critical deciding factor (Luo, 2013). The automotive industry, which stands as one of the major users of worldwide Mg, is taking steps in increasing the use of Mg parts in instrument panels, steering columns, seat frames, and transmissions housings as a part of the vehicle lightweighting program aimed at improving fuel efficiency and reducing CO_2 emissions during the whole life cycle of vehicles (Friedrich & Schumann, 2001; Kulekci, 2008). Mg is also considered a good candidate for the manufacture of biodegradable implants in the biomedical field since its elastic modulus (~45 GPa) and compressive strength are in the range of those of cortical bone and Mg 2+ ions released upon degradation of the material are highly biocompatible (Chen, Xu, Smith, & Sankar, 2014).

However, the application of monolithic magnesium in engineering is limited due to its intrinsic material weaknesses. The hexagonal close-packed (HCP) crystal structure of Mg allows only a few slip systems

to be activated at room temperature, mainly basal ⟨11$\bar{2}$0⟩ slip, hence, the plastic deformation is limited, and the ductility is low which is a condition that results in brittle failure. The elastic modulus of pure Mg (~45 GPa) and its hardness (~30, 40 HV) are significantly lower than those of competing structural alloys, and therefore, it can hardly be used in applications that require sustained mechanical loading or surface contact (Casati & Vedani, 2014). Besides, Mg has a high standard electrode potential (, 2.37 V vs. SHE) and is one of the most electrochemically active structural metals. This makes it very vulnerable to galvanic corrosion when exposed to more noble metallic elements, a problem that has facilitated the limited use of Mg in the past (Gupta & Ling, 2011; Tjong, 2013). Although conventional alloying with Al, Zn, Mn, and rare earth elements can reducethis problem to some extent, it usually results in a compromise between corrosion resistance, elevated-temperature strength, and ductility, thereby leaving a clear performance gap that alloying strategies alone cannot fill.

The idea of metal matrix composites (MMCs), in which reinforcing phases are strategically incorporated into a metal matrix, is a classic model of going beyond the property ceiling of monolithic metals (Lloyd, 1994). The combination of a Mg matrix that is ductile and damage-tolerant with a ceramic reinforcement that is hard, stiff, and thermally stable allows the creation of composites with combinations of specific strength, wear resistance, creep resistance, and dimensional stability that cannot be achieved by traditional alloying. Part of the load is transferred from the matrix to the reinforcement, grain refinement of the matrix by second-phase particles acting as heterogeneous nucleation sites, and dislocation generation at the matrix, reinforcement interface due to differential thermal contraction are the main mechanisms that lead to the improved mechanical properties of particulate-reinforced MMCs (Zhang & Chen, 2006). The level of improvement depends on the reinforcement volume fraction, particle size and morphology, the degree of interfacial bonding between the matrix and the reinforcement, and the processing route used (Wang et al., 2014).

A wide spectrum of ceramic materials has been investigated as reinforcements for Mg-based MMCs. Silicon carbide (SiC) particles and whiskers have been the most extensively studied, owing to their high modulus (~410 GPa), hardness (~28 GPa), and well-established compatibility with aluminium matrix systems, although their use in Mg is complicated by potential interfacial reactions that can degrade bonding quality. Alumina (Al2O3) in both microparticulate and nanoparticulate forms has demonstrated consistent improvements in hardness and tensile strength in Mg composites, attributed in part to Orowan strengthening and grain boundary pinning (Hassan & Gupta, 2005). Titanium diboride (TiB2), titanium carbide (TiC), and boron carbide (B4C) have been similarly explored, with documented gains in specific modulus and wear resistance (Appendino, Badini, Marino, & Tomasi, 1991). More recently, research attention has shifted towards transition metal oxides—including TiO2, ZnO, CuO, and Fe2O3—as candidate reinforcements for Mg matrices. This emerging category of reinforcements is attractive not only because of the intrinsic hardness and chemical stability of the oxide phases themselves, but also because of the possibility of thermally activated in-situ reactions between the oxide and the Mg matrix, which can generate novel secondary phases at the interfacial region and fundamentally alter the microstructural architecture of the composite.

Iron(III) oxide, or haematite (α-Fe_2O_3), is a red and black coloured mineral, one of the oldest and most widespread pigments used by mankind and a naturally-abundant, environmentally-friendly, and economically-viable corundum-type transition metal oxide. In its bulk form, haematite features a hardness of 5, 6.5 on the Mohs scale (roughly 5, 7 GPa Vickers), a Young's modulus of roughly 200, 230 GPa, a melting point of ~1565 °C, and high thermal and chemical stability under oxidising conditions (Makhlouf & Aliofkhazraei, 2015). Fe_2O_3 possesses the mechanical and physical properties to be used as a credible ceramic reinforcement for the hardness and stiffness of a Mg matrix. However, one point that is pivotal is that Fe2O3 is not only a passive reinforcement for a Mg matrix but also a chemically reactive participant in the composite system. The reaction between Fe_2O_3 and Mg is of thermic type and highly exothermic and thermodynamically favourable at the elevated temperatures that occur during sintering or casting: $3Mg + Fe_2O_3 \rightarrow 3MgO + 2Fe$ ($\Delta G^\circ << 0$). By the occurrence of this reaction, Fe_2O_3 particles may be partially or fully converted in situ into one set of finely dispersed MgO particles and elemental Fe, thus along with residual Fe2O3, newly formed MgO, and metallic Fe within the Mg matrix, a reinforcement arrangement that is fundamentally different from the composites that are reinforced by chemically inert ceramics (Dolatkhah, Golbabaei, Givi, & Molaiekiya, 2012).

The comprehensive evaluation of Fe2O3 reinforced Mg composites requires a suite of complementary characterisation techniques that probe different length scales and property domains. Optical microscopy (OM) serves as the foundational microstructural tool, providing direct visualisation of reinforcement particle distribution, size and morphology, matrix grain structure, grain boundary characteristics, interfacial zones, and the spatial homogeneity or clustering of the reinforcement phase across the composite cross-section [23]. Quantitative metallographic analysis via OM enables the measurement of average grain size as a function of Fe_2O_3 content, thereby allowing the grain refinement contribution to hardness enhancement to be assessed independently of other strengthening mechanisms (Vander Voort, 1999). Vickers microhardness testing (HV) is the most widely adopted method for assessing the hardness of particulate-reinforced MMCs due to its sensitivity to both matrix strengthening and the hardness contribution of the reinforcement phase itself (Handbook, 2000). The Vickers indentation load is typically chosen to encompass multiple reinforcement particles and matrix grains, yielding a composite hardness representative of the bulk material rather than individual phases. Density measurement by Archimedes' principle provides a critical quality metric for PM-processed composites: the ratio of experimentally measured bulk density to theoretical density, calculated using the rule of mixtures based on constituent densities, directly quantifies the residual porosity arising from incomplete sintering, particle clustering, or interfacial voids, all of which degrade mechanical performance (D). Monitoring density as a function of reinforcement volume fraction also allows the detection of any deviation from ideal mixing behaviour, which may indicate the onset of agglomeration or anomalous phase formation resulting from the thermite reaction.

While the Mg-MMC literature is rich in studies involving SiC and Al_2O_3 reinforcements, systematic investigation of Fe2O3 as a reinforcing phase in Mg matrices remains comparatively sparse, despite the compelling thermodynamic and microstructural arguments in its favour. The few studies that have examined iron oxide in light metal matrices have predominantly focused on Al-based systems or have been conducted in the context of in-situ reaction processing without isolating the independent contributions of reinforcement volume fraction to mechanical and physical properties. The dual-phase reinforcement scenario arising from the Fe2O3/Mg thermite reaction, producing both MgO and Fe in situ, introduces a level of microstructural complexity that demands careful characterisation to disentangle the individual contributions of each secondary phase to composite performance. Furthermore, the implications of the thermite reaction for composite density, specifically, whether the volumetric change associated with MgO formation and Fe release leads to measurable densification or porosity relative to a non-reactive reinforcement scenario, has not been systematically addressed in the published literature. The present study therefore aims to fill this gap by providing a comprehensive microstructural, mechanical, and physical characterisation of Fe2O3 reinforced Mg composites fabricated by PM, with emphasis on the interdependencies between reinforcement content, microstructural evolution, Vickers hardness, and composite density.

The primary objectives of this investigation are threefold: (i) to fabricate Mg, Fe2O3 composites over a systematic range of reinforcement volume fractions by powder metallurgy and to achieve consistent, reproducible consolidation; (ii) to characterise the microstructural evolution of the composites using optical microscopy, with particular attention to reinforcement distribution uniformity, matrix grain refinement behaviour, and evidence of in-situ interfacial reactions; and (iii) to quantify the effect of Fe_2O_3 addition on the Vickers hardness and bulk density of the composites and to rationalise the observed trends in terms of the governing microstructural mechanisms. Collectively, the findings of this study are intended to establish a foundational understanding of Fe_2O_3 as a reactive reinforcement in Mg matrices and to provide a scientific basis for the future design of iron-oxide-reinforced Mg composites with optimised mechanical and physical properties for lightweight engineering applications.

METHODOLOGY

Raw Materials

Powders of magnesium (Mg) and iron (III) oxide (Fe2O3) were chosen as matrix and reinforcement materials, coming from Nanografi and ZAG Chemistry, respectively. Before processing, no purification or pre-treatment was performed on the powders.

Composite Fabrication

Composites were made with powder metallurgy method, which was chosen due to the simplicity and the ability to obtain proper distribution of the reinforcement phases. Each batch was made from a total of 7 g of powder, while Fe_2O_3 was introduced at three reinforcement levels 5, 10 and 15 wt.% in order to capture a wide range of the final material properties. The rest of each batch was made of Mg powder. For powder mixing, the weighed Mg and Fe_2O_3 were placed in a beaker and the powders were mixed with a magnetic stirrer at 800 rpm for 30 minutes. This stage was indispensable for powder mixing as well as for breaking any agglomerates and ensuring that Fe_2O_3 particles were evenly distributed before consolidation. The obtained powder mixtures were then loaded into a steel die and cold-pressed at 300 MPa to make solid green compacts that can be handled and processed further.

RESULT AND DISCUSSION

Figure 1 depicts the experimentally determined densities of pure magnesium and magnesium/iron oxide (Mg/Fe_2O_3) composites with 5, 10, and 15 wt.% Fe_2O_3 fabricated through powder metallurgy. The density of pure Mg as the baseline without reinforcement was 1.67 g/cm³, which is a little lower than the theoretical density of pure magnesium (~1.74 g/cm³). This is a typical result of residual sintering-induced porosity in powder-processed samples a behavior that has been widely reported in sintered Mg-based systems (Parande, Manakari, Meenashisundaram, & Gupta, 2016; Sharma et al., 2025). At 5 wt.% Fe_2O_3, however, an unexpected and interesting point is the density of the composite, which decreases to 1.58 g/cm³ and is even less than that of the unreinforced matrix. Although the intrinsic density of Fe_2O_3 (~5.24 g/cm³) is significantly higher than that of Mg, the decline cannot be explained by the rule of mixtures alone. It may be due to particle agglomeration at low reinforcement fractions, which leads to the formation of voids in the local area and the incomplete bonding of the particle-matrix interface during sintering a similar situation reported by Kujur et al. (Kujur et al., 2021) in rare-earth oxide-reinforced Mg nanocomposites, where the non-uniform particle distribution at lower concentrations was found to be less efficient for densification. The density measured at 10 wt.% Fe_2O_3 increases to 1.69 g/cm³, slightly higher than that of pure Mg at 5 wt.%, and it still increases slightly to 1.70 g/cm³ at 15 wt.%. This suggests that at higher reinforcement fractions, the Fe_2O_3 particles with a higher density become more dispersed and contribute positively to the composite density, thus compensating for the lack of density at lower additions. The decrease in density during the processing of composites reinforced with oxides, and the subsequent recovery as the content of reinforcements increases, is a phenomenon that is not only observed in Mg systems with oxide reinforcements. Manakari et al. (Manakari, Parande, Doddamani, & Gupta, 2017) reported similar density variations in composites of Mg reinforced with hollow glass microballoons. They explained the behavior as a result of the interplay of two phenomena the increase in the density of the reinforcements and the generation of voids at the interfaces. Maryam et al. (Maryam et al., 2023) also found that the density of SiC/ZrO_2-reinforced AZ31 composites changed depending on the concentration and quality of the distribution of the reinforcement phase, emphasizing that the density of the reinforcements alone was not enough to predict the density of the composites. It should be noted that even at 15 wt.% Fe_2O_3, the composite density (1.70 g/cm³) is still less than 2 g/cm³, which is considered the upper limit for lightweight materials. This means that these composites are still suitable for the fabrication of lightweight structures for applications in aerospace and biomedical scaffolds. Taken together, the density results indicate that the optimization of the dispersion of reinforcements through processing parameters such as the duration of ball milling, sintering temperature, and compaction pressure will be crucial in achieving the theoretical density close to the rule-of-mixtures prediction for composites with a higher content of Fe_2O_3.

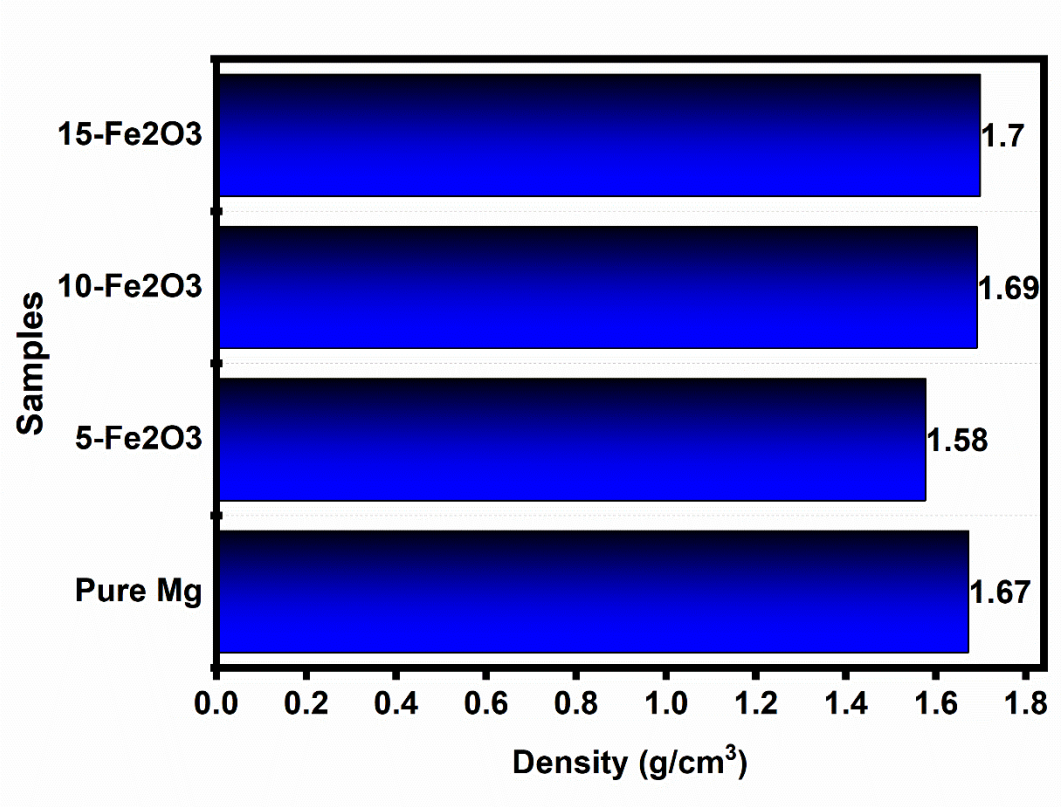


Figure 1. Densitiy values of the given composites

Generally, the hardness of the composite is found to grow steadily as the content of Fe2O3 increases (see Figure 2). Pure Mg has a hardness of 35.2 HV at baseline, which goes up a little to 36 HV at 5 wt.% of reinforcement, and then goes up more noticeably to 42.2 HV and 45.8 HV at 10 and 15 wt.% Fe_2O_3, respectively, which is a total enhancement of almost 30% compared to the non-reinforced matrix. The uninterrupted hardening behavior fits the strengthening mechanisms in metal matrix composites (MMCs) that are well understood, and these mechanisms are: load transfer from the softer Mg matrix to the harder ceramic Fe_2O_3 particles, grain boundary pinning, and generation of geometrically necessary dislocations due to the coefficient of thermal expansion (CTE) mismatch between the matrix and reinforcement (Mordike & Ebert, 2001). The relatively modest gain at 5 wt.% (only ~2.3%) compared to the larger increments at higher loadings suggests that at lower reinforcement fractions, incomplete particle dispersion or residual porosity may offset strengthening, a phenomenon similarly observed in Mg, CeO_2 composites where densification and hardness improvements were most pronounced only at higher reinforcement contents (Anand Babu, Kumaravel, & Manikandan, 2023). It has been shown that in-situ reactive sintering of Mg-based composites increases the hardness of the magnesium matrix by the presence of well-dispersed hard oxide particles (Yang et al., 2008). Meanwhile, RGO reinforced ZK61 Mg composites only 0.6 wt.% reinforcement resulted in a highest hardness of 79.9 HV (Liu, Wang, Du, Li, & Du, 2023). This indicates that nano-scale or chemically compatible reinforcements can be used to obtain higher hardness gains at lower fractions than the micron-scale oxides such as Fe_2O_3. Furthermore, microhardness of Mg composites fabricated by powder metallurgy and reinforced with SiC and Al2O3 also increased linearly with the incorporation of the ceramic particles (Karthick, Mathai, Tony, & Marikkannan, 2017). This is in accordance with the pattern as seen in Figure 2. When comparing to Figure 1 (density), a significant connection is found: the 5 wt.% Fe_2O_3 composite has the lowest density at 1.58 g/cm³ even less than that of pure Mg (1.67 g/cm³), which indicates a higher level of residual porosity in this reinforcement that leads to the almost negligible increase in hardness (35.2 → 36 HV). Studies on SiC-reinforced Mg-matrix composites by binder jetting have also demonstrated that densification and mechanical properties are closely linked, and that hardness enhancement is attributed to the extent of consolidation (Zhao, Zhang, Yang, Li, & Li, 2025). By raising the Fe2O3 content to 10 and 15 wt.%, density bounces back exceeding slightly that of pure Mg (1.69, 1.70 g/cm 3

). This is in line with the observation that Fe2O3 is a heavier material (theoretical density is ~5.24 g/cm 3), and at higher concentrations, it is able to fill the interparticle voids more effectively which, in turn, results in harder and more consolidated microstructures (Cornell & Schwertmann, 2003). The correlation between densification and hardness was also observed in the Mg, CeO_2 ceramics. In these ceramics, the ones with the largest amount of the reinforcing phase not only achieved the highest densification but also exhibited the highest microhardness values. Generally speaking, Figures 2 and 1 together confirm that in Mg/Fe_2O_3 composites, the best mechanical properties are obtained at higher Fe2O3 concentrations (≥10 wt.%), where both density and hardness levels are at their maximum, and the 15 wt.% specimen, in our opinion, achieves the reinforcement effect and microstructural consolidation to the maximum within the range of compositions that were studied.

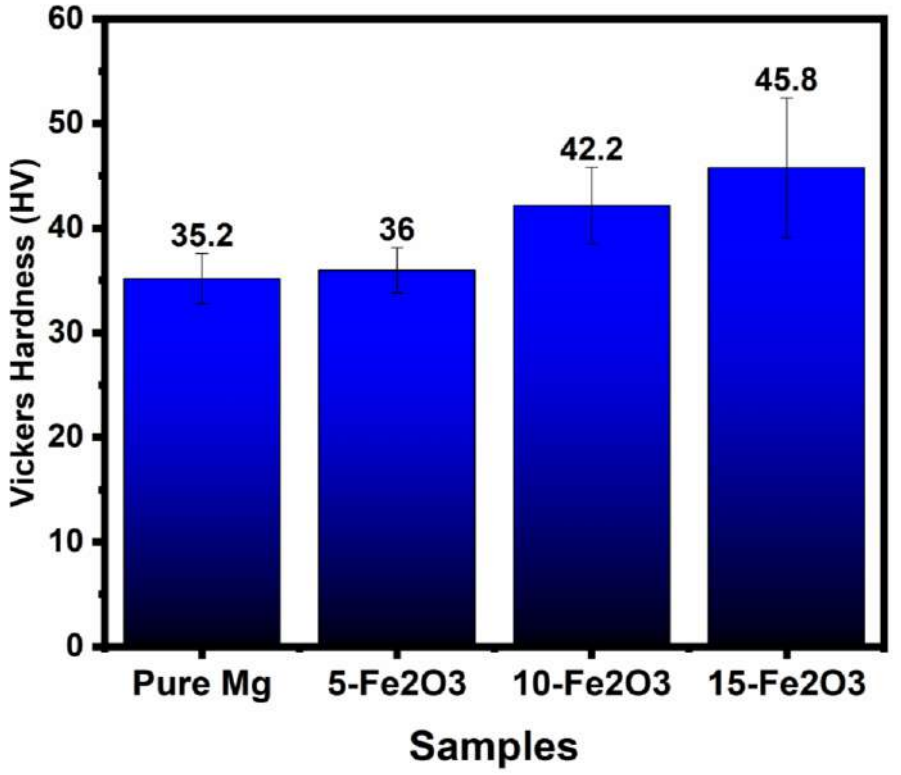


Figure 2. Microhardness values of the given composites

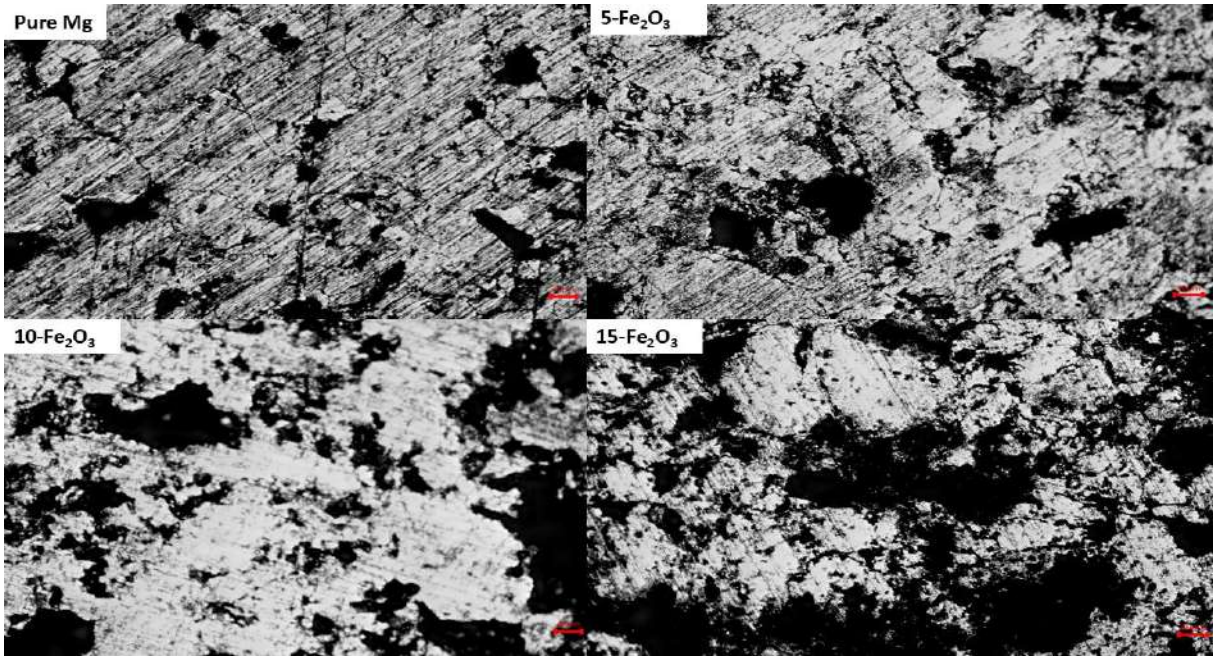
Figure 3 presents optical microscopy (OM) images of four samples — pure Mg, 5-Fe_2O_3, 10-Fe_2O_3, and 15-Fe_2O_3 — fabricated via powder metallurgy, and reveals a clear and progressive evolution in microstructural character with increasing Fe_2O_3 reinforcement content. In the **pure** Mg micrograph (top-left), the microstructure is dominated by a uniformly gray metallic matrix exhibiting characteristic parallel striations consistent with polishing-induced deformation lines along the basal slip planes of the hexagonal close-packed (HCP) Mg structure, while scattered irregular black regions indicate residual inter-particle porosity arising from incomplete sintering densification — a feature well-documented in sintered pure Mg compacts (Cornell & Schwertmann, 2003). In the **5-Fe_2O_3** composite (top-right), the matrix retains a broadly similar gray appearance to pure Mg, but subtle brighter micro-regions begin to emerge, representing sparsely distributed Fe_2O_3 particles; however, the reinforcement concentration at this level is insufficient for significant clustering, and the overall microstructure remains largely matrix-dominated with persistent porosity, consistent with the anomalously low density (1.58 g/cm³) observed in Figure 1 and the negligible hardness improvement seen in Figure 2. Studies on Mg–CeO_2 composites similarly showed that at low reinforcement fractions, the microstructure exhibited few defects only when optimal sintering was achieved, whereas poorly consolidated samples retained irregular void distributions (Deka, Mozafari, & Mallick, 2024). In the 10-Fe_2O_3 composite (bottom-left), a dramatic microstructural transformation is evident: the image is now characterized by highly distinct bright-white clusters — corresponding to Fe_2O_3 particle agglomerates — interspersed within a darker Mg matrix,

with the contrast between phases becoming unambiguous under reflected light illumination due to the higher reflectivity of the harder oxide phase relative to the metallic matrix. This phase-contrast behavior has been reported in Mg–SiC composites, where intermetallic or reinforcement phases were readily detectable as bright regions in optical micrographs due to their distinct reflectance relative to the Mg matrix (Faisal et al., 2024). The increase in bright-phase area fraction in the 10 wt.% sample correlates well with the simultaneous increase in density (1.69 g/cm³) and hardness (42.2 HV) observed in Figures 1 and 2, as denser packing of the harder Fe_2O_3 phase promotes matrix load transfer and grain boundary pinning. In the 15-Fe_2O_3 composite (bottom-right), the bright Fe_2O_3 clusters become even more prominent and better distributed across the field of view, indicating a higher volume fraction of reinforcement; nonetheless, localized agglomeration is visible, which is a known challenge in powder metallurgy-derived composites at higher reinforcement loadings. Similar agglomeration of ceramic reinforcements in Mg matrices has been reported in Mg–Al_2O_3 systems, where a high number of processing turns were needed to fully disperse reinforcement clusters into the matrix (Castro, Pereira, Figueiredo, & Langdon, 2019). The persistent dark (black) regions in all four samples represent residual porosity and unfilled inter-particle voids, which diminish slightly from the 5 wt.% to the 15 wt.% samples in accordance with the density trend in Figure 1 — reflecting improved matrix-reinforcement contact and partial pore closure at higher Fe_2O_3 contents. This observation aligns with Mg–Al_2O_3 composites produced by hot pressing, where a homogeneous and dense microstructure was only

achieved at optimized reinforcement fractions under adequate sintering pressure (Ercetin & Pimenov, 2021). Taken together, Figures 1, 2, and 3 present a consistent and mutually corroborating narrative: the anomalously low density and near-zero hardness gain at 5 wt.% Fe_2O_3 corresponds to a microstructure that remains largely un-reinforced with high porosity, while the superior density and hardness at 10–15 wt.% Fe_2O_3 is microstructurally explained by the increased area fraction of bright Fe_2O_3 clusters, improved inter-particle bonding, and reduced porosity observed in Figure 3.

Figure 3. Optic microscope images of the given composites

CONCLUSION



Fe_2O_3 reinforced magnesium (Mg) matrix composites were successfully fabricated by powder metallurgy technique in this work, and the influence of reinforcement content on microstructural, physical and mechanical properties of the composites was thoroughly investigated. The results clearly proved that Fe_2O_3 addition has a very important role in changing the densification behavior, hardness response and microstructural evolution of Mg based composites. The powder metallurgy route was

proved to be an effective method for fabrication of lightweight Mg composites with relatively uniform distribution of reinforcements and acceptable consolidation characteristics.

From the density analysis, a reduction of the density at 5 wt.% reinforcement was first due to the addition of Fe_2O_3 because of an incomplete densification, localized particle agglomeration and the formation of residual porosity during compaction and sintering . The minimum value of density was observed for 5 wt.% Fe_2O_3 composite and it was lower than that of pure Mg (1.58 g/cm³). However, increasing the reinforcement ratio to 10 wt.% and 15 wt.% enhanced the density values to 1.69 and 1.70 g/cm3, respectively. The behavior indicated that higher reinforcement fractions led to better particle packing, improved matrix, reinforcement interaction, and partial pore closure during sintering. It is noted that all the composites retained densities below 2 g/cm^3 even after the addition of relatively dense Fe_2O_3 particles thus preserving the lightweight features required for aerospace, automotive and biomedical applications.

The Vickers hardness results showed that the hardness increased continuously with the increasing Fe_2O_3 content. The pure Mg's hardness value was 35.2 HV and the 15 wt.% Fe 2 O 3 composite's hardness was 45.8 HV, with an increase in hardness of about 30%.The increased hardness was attributed to different strengthening mechanisms such as load transfer from the ductile Mg matrix to the hard Fe_2O_3 particles, pinning of the grain boundaries, increased resistance to dislocation motion, and improved densification at higher levels of the reinforcement. The limited improvement in hardness at 5 wt.% Fe_2O_3 was directly associated with the presence of higher porosity and poor distribution of reinforcement in the matrix.

The optical microscopy observations corroborated the density and hardness results by showing a gradual increase in the quantity and distribution of bright Fe2O3-rich regions in the Mg matrix with increasing reinforcement content. The pure Mg and 5 wt.% Fe_2O_3 samples showed considerable porosity and limited reinforcement visibility, while the 10 wt.% and 15 wt.% composites showed more pronounced reinforcement regions and improved matrix continuity. With increasing Fe_2O_3 content, the overall microstructure turned more compact and homogeneous, but some local agglomeration was observed at higher reinforcement levels.

In general, the present study showed that Fe_2O_3 is a promising reinforcement material for Mg based metal matrix composites manufactured by means of powder metallurgy. Among the investigated compositions, the 15 wt.% Fe_2O_3 composite showed the best combination of hardness improvement and densification behavior while retaining lightweight properties. The results shed light on oxide-reinforced Mg composites and provide a scientific basis for further research on optimizing processing conditions, improving reinforcement dispersion, and investigating other properties like wear resistance, corrosion behavior, and mechanical performance under advanced service conditions.

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RISK ASSESSMENT OF THE IMDG CODE DANGEROUS GOODS SEGREGATION PROCESS AT PORTS BY THE FINE-KINNEY METHOD

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ABSTRACT

Safe handling and storage of dangerous goods in ports are essential to avoid fires, explosions, leaks, and environmental damage that may result from the interaction of different hazard classes of dangerous goods. The aim of this study is to identify the risks that may arise in the dangerous goods segregation process in ports within the scope of the IMDG Code and to prioritize them using the Fine-Kinney method for risk assessment. In this study, the main risk sources identified included incorrect classification of dangerous goods, labeling and marking errors, storage of incompatible dangerous goods in the same area, incorrect application of segregation distances, improper stowage, incorrect container positioning, personnel competence, information transfer, port traffic, and emergency preparedness. Risk scores were calculated based on probability, exposure frequency, and severity parameters in the Fine-Kinney method. From the initial assessment, it was concluded that the risk scores range from 135 to 720, and the storage of incompatible dangerous goods in the same area, incorrect classification, and incorrect application of segregation distances were at the highest risk level with a score of 720. The introduction of the proposed control measures is expected to reduce risks by between 77.8% and 91.7%. The results indicate that a feasible approach to identify and mitigate risks related to dangerous goods in ports can be achieved by combining the technical segregation requirements of the IMDG Code and the risk prioritization approach of the Fine-Kinney method. The study additionally emphasizes the necessity of full implementation of physical segregation, personnel training, digital monitoring, routine inspections, and emergency preparedness.

Keywords: Dangerous Goods, IMDG Code, Segregation, Fine-Kinney, Risk Assessment.

INTRODUCTION

Maritime transport is one of the main components of international trade, and a large part of the world's cargo movement is carried out through ports (Eski & Tavacioglu, 2021). In addition, due to increased industrial production, diversification of global supply chains, and extensive use of chemicals, the carriage of dangerous goods (DG) has also reached a significant share within maritime transport (Eski & Tavacioglu, 2024; Mullai, 2007). Safe handling and storage of these flammable, explosive, toxic, corrosive, and environmentally harmful substances are vital for the health and safety of workers and environmental sustainability (Eski, 2026; Eski & Tavacioglu, 2022a). Hence, management of DG in port operations in accordance with the international and national regulations has become obligatory (Eski & Tavacioglu, 2021).

DG operations at ports consist of loading, unloading, storage, stowage, segregation, and shipment processes (Eski & Tavacioglu, 2022b). Within these processes, the segregation of DG is one of the fundamental risk control methods applied to prevent interaction between cargoes with different hazard classes. Proper segregation of DG that could react with each other or cause secondary hazards such as fire, explosion and toxic gas formation at proper distances or with physical barriers is an essential part of preventing potential accidents (IMO, 2024).

The basic international regulation for the maritime transport of packaged DG is the International Maritime Dangerous Goods (IMDG) Code (Eski & Tavacioglu, 2021). The code has elaborate provisions for not only the classification but also the segregation of DG (Zhang et al., 2020). The IMDG

Code's segregation provisions are defined to minimise the risks of chemical reactions through the safe storage and transport of substances with different hazard classes (IMO, 2024; Zhang et., 2020). Systematic methods should be used to evaluate the risks that may occur in the process of segregation.

Risk assessment methods in occupational health and safety are important decision-support tools to identify and prioritise hazards. One of the methods is the Fine-Kinney method (Pajić & Andrejić, 2023). It provides a quantitative risk score by evaluating the risk level using parameters such as the probability of occurrence (P), frequency of exposure (F), and severity of possible consequences (S) (Kuleshov, Yu Skuba & Ignatovic, 2021). It enables the comparison of different risk types and provides effective results in prioritising improvements. Therefore, it is widely preferred in studies dealing with port operations (Erküvün & Yorulmaz, 2026; Bayram & Kaya, 2022; Çınar, Solmaz & Çakmak, 2021).

The aim of this study is to determine the risks that may be encountered in the DG segregation process in ports within the framework of the IMDG Code provisions and to evaluate them using the Fine-Kinney method. The study investigates the main hazard sources affecting the segregation process, defines the risk levels, determines the high-priority risks and proposes recommendations for control measures in compliance with the IMDG Code. In this respect, the study aims to contribute to the improvement of DG management in ports, the enhancement of operational safety, and the prevention of potential industrial accidents.

METHODOLOGY

Scope of the research

This study aims to identify and prioritise the risks that may arise during the DG process in port operations. The research covers the processes of acceptance, temporary storage, segregation, and preparation for the shipment of DG transported by sea within the port area. The study evaluates risks such as fire, explosion, toxic gas release, chemical reactions, and environmental pollution that may occur due to incompatibilities between DG.

The risk assessment was conducted based on the segregation provisions contained in the IMDG Code developed by the International Maritime Organization (IMO). In this context, DG classes, segregation tables, exceptions and special provisions were considered, and potential hazards encountered in port operations were identified.

DG segregation under the IMDG Code

The IMDG Code is an international regulation established to ensure the safe transport of DG by sea. Under the code, DG are classified into nine main hazard classes according to their physical and chemical properties, and rules for transport, stowage, labelling, and segregation are defined for each class.

Segregation procedures applied in ports aim to prevent the reactions of cargoes from different hazard classes with one another. The segregation levels included in the IMDG Code are generally "No segregation required", "Away from", "Separated from", "Separated by a compartment or hold from", and "Separated longitudinally by a complete compartment or hold from". These segregation levels define the minimum safety criteria for whether DG is stored in the same storage area or in different storage regions.

The implementation of these rules in port management depends on accurate cargo classification, identification of suitable storage areas, adequate personnel training, information sharing, and effective operational planning.

Fine-Kinney risk assessment method

In this study, the Fine-Kinney method was used to assess risks. The Fine-Kinney method is a semi-quantitative risk analysis method widely used in occupational health and safety practices (Jain, Leka & Zwetsloot, 2018). The method considers three basic parameters for each hazard (Kinney & Wiruth, 1976):

Probability (P): The likelihood of a hazardous event occurring.

Frequency (F): The frequency with which employees or the system is exposed to the hazard.

Severity (S): The magnitude of the consequences that may arise if the event occurs.

The risk score is calculated using the following equation (Kinney & Wiruth, 1976):

Risk score (R) = Probability (P) x Frequency of exposure (F) x Severity (S)

Table 1 presents the probability scale of the Fine-Kinney method (Kinney & Wiruth, 1976).

Table 1. The probability scale.

Value (P)	Category	Description
0.2	Practically Impossible	The hazardous event is considered virtually impossible under normal operating conditions. It would require exceptional or highly unlikely circumstances to occur.
0.5	Unlikely	The probability of occurrence is very low but cannot be completely ruled out.
1	Quite Unlikely	The event is unlikely to occur under normal conditions but remains possible.
3	Unusual but Possible	The event is not common; however, it may occur under certain operating conditions or has been observed occasionally.
6	Quite Possible	The event has a high likelihood of occurring unless appropriate preventive measures are implemented.
10	Almost Certain	The event is expected to occur frequently or is considered nearly inevitable.

Table 2 presents the frequency scale of the Fine-Kinney method (Kinney & Wiruth, 1976).

Table 2. The frequency scale.

Value (F)	Category	Description
0.5	Very Rare	Once a year or less
1	Quite Rare	Once or several times a year
2	Rare	Once or several times a month
3	Occasional	Once or several times a week
6	Frequent	Once a day or more
10	Continuous	Continuous exposure or more than once per hour

Table 3 presents the severity scale of the Fine-Kinney method (Kinney & Wiruth, 1976).

Table 3. The severity scale.

Value (S)	Category	Description
1	Noticeable	Minor consequences; no injury or negligible damage.
3	Significant	Minor injury, low work time loss, minor property damage, and first aid treatment are required.
7	Serious	Major injury, significant damage, medical treatment required, and lost workdays.
15	Very Serious	Permanent disability, loss of limb, or considerable environmental impact.
40	Extremely Serious	Fatality, total permanent disability, or severe environmental damage.
100	Catastrophic	Multiple fatalities and/or a major environmental disaster.

Table 4 presents the risk score, risk level, and required action (Kinney & Wiruth, 1976).

Table 4. The risk scale.

Risk Score (R)	Risk Level	Required Action
R < 20	Acceptable Risk	Immediate corrective action may not be required. Existing control measures should be maintained.
20 < R < 70	Possible Risk	The risk should be included in the action plan, and corrective measures should be implemented in a planned manner.
70 < R < 200	Significant Risk	The risk should be closely monitored and eliminated through the annual action plan.
200 < R < 400	High Risk	Corrective actions should be implemented through a short-term action plan.
R > 400	Very High Risk	Work should be suspended immediately until adequate control measures are implemented.

This method has not only determined the magnitude of existing risks but has also revealed which risks require priority intervention.

Risk assessment process

The risk assessment process applied in the research consists of the following stages:

- Review of DG segregation rules under the IMDG Code.
- Analysis of the segregation process in port operations.
- Identification of potential hazards during segregation.
- Determination of the Fine-Kinney parameters for each hazard.

- Calculation of risk scores.
- Ranking of risks according to their severity.
- Recommendation of measures to control risk in accordance with the provisions of the IMDG Code.

The main risks assessed in the study included incorrect cargo classification, keeping incompatible cargo in the same storage area, container labeling errors, damaged packaging, lack of personnel knowledge, inadequate operational communication, insufficient emergency preparedness, and the impact of environmental conditions on segregation safety.

The findings were evaluated both to determine the current risk levels and to develop preventive and corrective measures that can be implemented in ports.

FINDINGS AND DISCUSSION

In this study, the risks that may arise during the DG segregation process in ports were analyzed using the Fine-Kinney risk assessment method, based on the segregation rules defined in the IMDG Code. In the assessment, probability (P), exposure frequency (F), and severity (S) values were determined for each hazard, and risk scores were calculated. The risk score was obtained using the relationship P x F x S.

The assessment of the DG segregation process considered the following main sources of risk: incorrect classification of cargo, co-storage of incompatible DG, incorrect container positioning, labeling and marking errors, acceptance of damaged packaging, lack of knowledge of personnel regarding IMDG Code provisions, inadequate operational communication, improper stowage, insufficient emergency equipment, and environmental conditions.

Table 5 presents the comparison of existing and residual risks in the DG segregation process. The risk score was calculated using the equation R = P x F x S. The risk reduction percentage was calculated using [(Existing risk – Residual risk) / Existing risk] x 100. The new P, F, and S values represent illustrative residual risk values assuming that the proposed control measures are effectively implemented. In a real field study these values must be re-evaluated by expert judgment, historical accident/incident data, and operational data.

Under the Fine-Kinney method, the risk score was calculated by multiplying the probability (P), exposure frequency (E), and severity (S) values. Initial assessment results showed that risk scores ranged from 135 to 720. In particular, the storage of incompatible DG in the same area, the incorrect classification of DG, and the incorrect application of segregation distances were identified as activities with the highest risk level, scoring 720 points. These risks were categorized as “very high risk” according to the classification used in the study (see Table 4).

Findings regarding the segregation of DG

The findings show that the most critical risks in the DG segregation process are directly related to the incorrect application of the segregation rules specified in the IMDG Code. The fact that the risks of storing incompatible DG in the same area and incorrect application of segregation distances received a score of 720 points reveals that simply keeping cargo in physically segregated areas in ports is not sufficient.

The risk posed by DG stems not only from the individual properties of the substances but also from their interactions with each other. In particular, the presence of flammable, oxidizing, and corrosive substances together under unsuitable conditions can lead to secondary and cascading consequences such as fire, explosion, toxic gas formation, or environmental pollution. Therefore, the segregation process must be based not only on the physical distance in the storage area but also on the DG UN number, the proper shipping name, the hazard class, the secondary hazard (if any), and the specific segregation provisions laid down in the IMDG Code.

The risk of incorrect classification also ranked in the highest risk group, with 720 points. Incorrect classification of DG is a chain reaction error that can affect all subsequent operational processes.

Misclassification can cause hazards, including wrong labeling, incorrect stowage, wrong storage area selection, and exposure to incompatible substances. The UN number, proper shipping name, and hazard class should therefore be regarded as a critical control point in the DG acceptance process.

Labeling, marking, and documentation risks

Labeling and marking errors were initially assessed at a "very high risk" level with a risk score of 540. Incorrect labeling or the absence of necessary markings on DG containers significantly increases operational risk, even though the physical characteristics of the cargo remain unchanged. This is because port personnel largely determine the necessary safety measures during transport and storage based on the cargo classification and markings.

We expect the proposed systematic labeling checks, isolation of unsuitable containers, and pre-operational verification measures to reduce this risk from 540 points to 45 points. Accordingly, the proposed measures achieve a 91.7% reduction in risk. This result demonstrates that documentation and labeling controls are relatively low-cost measures with high-risk reduction potential.

Similarly, the partial transmission of DG information to operational personnel was initially scored at 270 points and reduced to 45 points by the implementation of proposed standard shift handover procedures and digital information sharing. Standardized communication procedures and digital systems can significantly help reduce the risks from human and information flow.

Table 5. Comparative assessment of existing and residual risks.

No.	Hazard / Risk Source	Existing Control Measures	P	F	S	Existing Risk	Proposed Additional Control Measures	New P	New F	New S	Residual Risk	Risk Reduction (%)
1	Storage of incompatible dangerous goods in the same area	General yard plan and personnel control	3	6	40	**720**	Physical segregation according to the IMDG Code segregation requirements; digital compatibility check	1	3	40	**120**	**83.3**
2	Incorrect classification of dangerous goods	Manual verification of cargo documents	3	6	40	**720**	Double-checking the UN No., hazard class, and Proper Shipping Name	1	3	40	**120**	**83.3**
3	Incorrect positioning of containers	Manual monitoring by yard personnel	3	6	15	**270**	Digital container tracking system and automated position verification	1	3	15	**45**	**83.3**
4	Errors in labeling and marking	Visual inspection before operations	6	6	15	**540**	Systematic label verification and isolation of non-compliant containers	1	3	15	**45**	**91.7**
5	Acceptance of damaged packages or containers	Visual inspection at gate entry	3	3	40	**360**	Detailed acceptance inspection and establishment of an isolation area for damaged cargo	1	2	40	**80**	**77.8**
6	Insufficient knowledge of the IMDG Code among personnel	Initial and periodic training	6	6	15	**540**	Regular IMDG training, refresher training, and practical emergency drills	1	3	15	**45**	**91.7**

No.	Hazard / Risk Source	Existing Control Measures	P	F	S	Existing Risk	Proposed Additional Control Measures	New P	New F	New S	Residual Risk	Risk Reduction (%)
7	Incomplete communication of dangerous goods information to operational personnel	Verbal and written shift handover	3	6	15	**270**	Standardized shift handover forms and digital information sharing	1	3	15	**45**	**83.3**
8	Improper stowage and storage	General stowage procedures	6	6	15	**540**	IMDG-compliant stowage plan and regular yard inspections	1	3	15	**45**	**91.7**
9	Insufficient or inaccessible emergency response equipment	Periodic equipment inspections	3	3	40	**360**	Positioning emergency equipment at accessible locations and increasing inspection frequency	1	2	40	**80**	**77.8**
10	Inadequate measures against fire and explosion risks	Fire protection systems	3	3	40	**360**	Periodic testing of fire detection and suppression systems and emergency drills	1	2	40	**80**	**77.8**
11	Heavy traffic and operational interaction within the port area	General traffic regulations	6	6	15	**540**	Separating dangerous goods areas from traffic flows and implementing controlled vehicle access	1	3	15	**45**	**91.7**
12	Adverse weather conditions affecting dangerous goods operations	Operator observation	3	3	15	**135**	Meteorological monitoring and restricting operations under critical weather conditions	1	2	15	**30**	**77.8**
13	Incorrect application of segregation distances	Operational personnel checks	3	6	40	**720**	Pre-operation verification of IMDG segregation requirements and digital compatibility checking	1	3	40	**120**	**83.3**
14	Insufficient inspection and monitoring of dangerous goods	Periodic yard inspections	3	6	15	**270**	Checklists, scheduled inspections, and recording of non-conformities	1	3	15	**45**	**83.3**
15	Inadequate emergency response and evacuation procedures	Existing emergency response plan	3	3	40	**360**	Updating emergency plans and conducting regular evacuation drills	1	2	40	**80**	**77.8**

Personnel competence and human factors

Insufficient knowledge of the IMDG Code among personnel has been identified as a significant risk factor, with a risk score of 540. It is not enough for personnel working in DG operations to possess only general knowledge of occupational health and safety. Personnel must have sufficient knowledge of the classification, labeling, marking, storage, segregation of DG, and emergency response procedures.

Regular IMDG training, refresher training, and practical emergency drills are recommended for this risk. Training and competency development activities focusing on the human factor effectively reduce the risk score to 45 and achieve a 91.7% risk reduction after implementing control measures.

However, training activities should not be considered a one-off application. In view of the constantly changing nature of port operations, personnel changes, new equipment, and different types of DG, periodic training and practical drills are essential.

Storage, stowage, and container positioning risks

Improper stowage and storage were scored 540 points, while incorrect container positioning was scored 270 points. Improper stowage of DG containers not only increases the risk of physical damage but can also lead to incompatible cargoes coming close together and violating segregation provisions.

It is estimated that the risk of improper stowage can be reduced from 540 points to 45 points, representing a 91.7% reduction, by preparing stowage plans in accordance with the IMDG Code and conducting regular field inspections. For the risk of incorrect positioning, it is estimated that the risk can be reduced from 270 points to 45 points by implementing applications such as digital container tracking systems and automated position verification.

These results indicate that ports should not limit DG management to physical area arrangements alone. In addition to physical isolation, timely information on the location of containers as well as real-time monitoring of cargo are key risk management tools, especially in ports with high operational intensity.

Damaged containers and emergency risks

The acceptance of damaged packaging or containers is assessed with a risk score of 360 points. Allowing a damaged container into the port area can increase the likelihood of accidents such as leaks, spills, fires, or toxic substance releases. Therefore, during the DG acceptance phase, both document control and the packaging and containers' physical condition must be checked.

It has been assessed that strengthening inbound control, creating an isolation area for damaged cargo, and implementing emergency response procedures can reduce the risk score from 360 to 80, achieving a 77.8% reduction in risk.

Insufficient or inaccessible emergency equipment and inadequate measures against fire and explosion risks were also initially assessed with a score of 360. To control these risks, it is recommended that fire detection and suppression systems be tested periodically, that spill and leak response equipment be readily available, and that regular emergency drills be conducted.

Effects of port traffic and environmental factors

Heavy traffic and operational interaction in the port area were evaluated as high risk with a score of 540 points. Continued heavy vehicle and equipment traffic in DG-carrying areas can generate secondary risks such as collisions, container damage, cargo overturning, and ultimately, release of DG.

It is predicted that this risk can be reduced to 45 points, or 91.7%, by isolating DG storage areas from general traffic flow as much as possible, implementing controlled vehicle entry and exit, and applying speed limits. This finding demonstrates that DG safety is not limited to practices within DG areas; overall port traffic and area planning are also part of risk management.

Adverse weather conditions affecting DG operations were assessed as a "significant risk" with a score of 135. Regularly monitoring meteorological conditions and limiting operations during critical weather

conditions could reduce this risk score to 30. This result suggests that assessing environmental conditions before operation can be effective in reducing exposure frequency.

Comparing existing and residual risks

The second Fine-Kinney assessment, conducted after implementing risk mitigation measures, shows a decrease in risk scores across all risk groups. It is predicted that three key risks –storage of incompatible DG in the same area, incorrect classification, and incorrect application of segregation distances – initially at the "very high risk" level with 720 points, can be reduced to 120 points after control measures are implemented. Thus, an 83.3% reduction is achieved in these risks.

For risks such as labeling and marking errors, lack of personnel knowledge of the IMDG Code, improper stowage, and heavy traffic in the port area, a 91.7% reduction was achieved. This result shows that organizational and operational control measures can significantly manage these risks.

However, risks such as acceptance of damaged containers, insufficient emergency equipment, fire and explosion risks, and insufficient emergency and evacuation procedures are still at a residual risk level of 80 points. The main reason for the residual risk level is that the severity coefficient (S) for these risks is still at 40. Thus, the measures can lower the event's likelihood and exposure frequency, but they cannot prevent severe consequences like death, serious injury, or environmental damage if it happens.

This finding highlights the importance of the difference between eliminating risk and reducing it to an acceptable level in DG operations. Especially for DG with a high severity of consequences, improving firefighting, emergency response, leak control, evacuation, and environmental response capabilities is necessary in addition to implementing preventive measures.

The evaluation focuses on the combination of the IMDG Code and the Fine-Kinney methodology

One of the key findings of this study is that the IMDG Code and the Fine-Kinney method perform two complementary functions. The IMDG Code sets out the technical and operational requirements for the classification, transport, handling, stowage, and segregation of DG, while the Fine-Kinney method allows for the quantitative prioritization of risks that may arise from the non-implementation or inadequate implementation of these requirements.

From this perspective, applying only the provisions of the IMDG Code may not be sufficient for prioritizing risks. Similarly, a general risk assessment using only the Fine-Kinney method may be insufficient to identify specific incompatibilities between DG. The combined use of these two approaches provides answers to both the question of "Which segregation rule should be applied?" and "What is the priority of the risk arising from the violation of this rule?"

When segregating DG, it is not sufficient to consider only the hazard class; each cargo's UN number, proper shipping name, packing group, subsidiary hazard (if any), and specific segregation provisions specified in the IMDG Code must also be considered.

General discussion

Overall, the findings indicate that the risks in the DG segregation process at ports are multifaceted. While a significant portion of the risks stem from physical storage conditions, misclassification, incorrect labeling, deficiencies in information transfer, personnel competence, operational traffic, and emergency preparedness also directly affect the risk level.

It is considered that, especially in activities with very high-risk levels, measures based solely on personal protective equipment or employee attention will not be sufficient. To mitigate risks, engineering controls, physical segregation, digital cargo tracking systems, standard operating procedures, personnel training, periodic inspections, and emergency preparedness should be implemented together.

The results show that implementing the proposed control measures can achieve a reduction in risk scores ranging from 77.8% to 91.7%. However, it should be noted that these percentages are based on sample Fine-Kinney values and should be recalculated in a real field application using expert assessments, past accident records, near-miss accidents, and operational statistics.

In this respect, the IMDG Code requirements should be regarded as both regulatory and as part of an integrated risk management approach to the safe handling of DG in ports. The combined application of the technical segregation rules of the IMDG Code and the risk prioritization approach of Fine-Kinney provides an integrated framework for port authorities to identify critical risks, allocate funds to priority risks, and evaluate the effectiveness of the control measures implemented.

CONCLUSION

This study examines the risks that may arise in the DG segregation process in ports, within the scope of the IMDG Code, and evaluates them using the Fine-Kinney method for risk assessment. The study considers the classification, labeling, and marking of DG, container positioning, stowage and storage conditions, application of segregation distances, personnel competence, information transfer, port traffic, and emergency preparedness as key risk sources. The findings show that the risks in the DG segregation process stem not only from the physical and chemical properties of the substances but also from errors and deficiencies in operational processes.

The risk scores obtained in the first assessment based on the Fine-Kinney method were between 135 and 720. The activities with the highest risk level of 720 points were storing incompatible DG in the same area, incorrectly classifying DG, and not applying segregation distances correctly. This result demonstrates that the correct application of the segregation provisions in the IMDG Code is critically important for DG safety in ports. In addition, high-priority risks include errors in labeling and marking, lack of personnel knowledge of the IMDG Code, improper stowage, and heavy traffic in the port area.

A residual risk assessment after implementation of the proposed control measures showed a significant risk reduction in all risk groups. The risk reduction was between 77.8% and 91.7%, with a 91.7% reduction particularly in the risks arising from labeling and marking errors, personnel competence, improper stowage, and port traffic. Risks initially assessed at 720 points, such as the storage of incompatible DG in the same area, incorrect classification, and improper application of segregation distances, were projected to be reduced to 120 points following the proposed measures. However, risks with potential for fire, explosion, leakage, and serious environmental impacts were not eliminated, and residual risk levels were maintained. This situation emphasizes the importance of effective emergency response and preparedness systems in addition to preventive measures for high-consequence DG risks.

One of the key findings of the study is that the combined use of the IMDG Code and the Fine-Kinney method offers a complementary approach to assessing DG risks in ports. While the IMDG Code sets out the technical requirements for the classification, transport, handling, stowage, and segregation of DG, the Fine-Kinney method allows for the prioritization of risks that may arise from the non-implementation or inadequate implementation of these requirements. Therefore, in DG management, simply ensuring compliance with regulations is not sufficient; it is necessary to identify critical risks and regularly evaluate the effectiveness of control measures. In particular, the combined application of physical segregation, standard operating procedures, personnel training, digital container tracking systems, periodic inspections, and emergency drills provides an integrated approach to risk mitigation.

The study has some limitations. Firstly, the probability, exposure, and severity values used in the Fine-Kinney method are assessment-based and should not be interpreted as an absolute indicator of safety. Furthermore, the residual risk values obtained after the proposed measures are based on the assumption that the measures have been effectively implemented. Therefore, supporting the results obtained in this study with real field data, past accident and near-miss records, inspection results, and expert assessments will increase the reliability of the risk scores.

Future studies are proposed to compare different port and terminal operations, re-evaluate Fine-Kinney parameters using real accident and near-miss data, and integrate IMDG segregation rules based on UN numbers into digital decision support systems. Moreover, the use of other risk assessment techniques such as AHP, FMEA, HAZOP, or Bow-Tie, in combination with the Fine-Kinney method, and the use of fuzzy logic-based approaches in the case of high-uncertainty may result in more comprehensive risk models. For example, the combination of real-time container tracking systems, electronic DG notifications, and automated IMDG compliance checks with AI-powered decision systems can enable critical errors, such as the placement of non-compliant cargo in the same area, to be detected before

operations take place. To summarize, the combination of the technical segregation requirements of the IMDG Code and the quantitative risk prioritization method of the Fine-Kinney method offers a feasible and improvable way to identify, control, and monitor the effectiveness of control measures against critical risks in the DG segregation process at ports.

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ANALYSIS OF THE NITRO-SUBSTITUTED HYDRAZONE DERIVATIVE ACCORDING TO VEBER AND EGAN RULES USING THE SWISSADME PLATFORM

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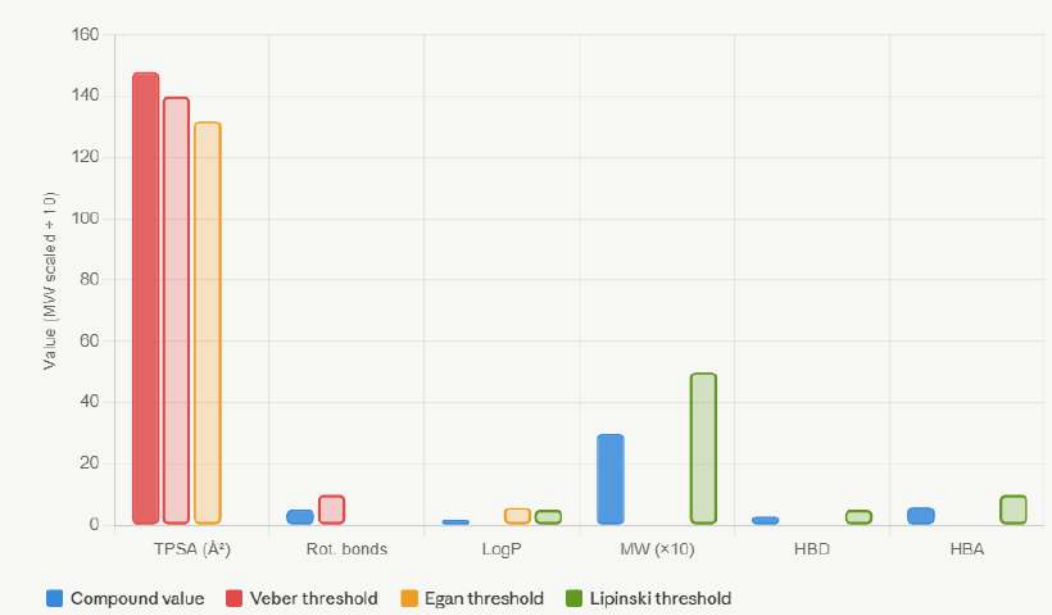
In this study, the compliance of (E)-5-(2-(4-nitrobenzylidene)hydrazineyl)isophthalic acid, the nitro-substituted hydrazone derivative, with Veber and Egan rules was investigated using the SwissADME platform. These rules are important for evaluating the oral bioavailability and membrane permeability potential of drug-like compounds. Although (E)-5-(2-(4-nitrobenzylidene)hydrazineyl)isophthalic acid complies with Lipinski's rule with zero violations, the SwissADME results showed violations related to the Veber and Egan rules. The main reason for these violations is the high TPSA value of (E)-5-(2-(4-nitrobenzylidene)hydrazineyl)isophthalic acid. TPSA, or topological polar surface area, is an important physicochemical parameter that reflects the polarity of a molecule. A high TPSA value usually indicates stronger polar interactions and a higher number of polar functional groups. In (E)-5-(2-(4-nitrobenzylidene)hydrazineyl)isophthalic acid, the presence of the nitro group increases the polar character of the compound. As a result, the increased polarity may reduce the ability of this compound to pass through biological membranes. This can negatively affect its gastrointestinal absorption and oral bioavailability. According to the SwissADME results, Compound showed low GI absorption, which supports this interpretation. The Veber and Egan violations suggest that Molecule 3 may have certain limitations as an orally active drug candidate. However, this does not completely exclude its biological potential. Instead, it indicates that further structural optimization may be required to improve its pharmacokinetic properties. Overall, the results show that the nitro group has a significant influence on

the ADME behavior of Molecule. Therefore, this compound should be evaluated carefully in future computational and experimental studies.



Keywords: Nitro group, Veber rule, Egan rule, TPSA, GI absorption, SwissADME.

ARTIFICIAL INTELLIGENCE-POWERED DIGITAL TWINS FOR SMART ENTERPRISES ENHANCING OPERATIONAL INTELLIGENCE THROUGH REAL-TIME VIRTUAL MODELING

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ABSTRACT

Digital Twin technology has emerged as a transformative innovation that enables organizations to create virtual representations of physical assets, industrial systems, and business processes. When integrated with Artificial Intelligence, Digital Twins evolve into intelligent systems capable of continuous monitoring, predictive analytics, autonomous optimization, and real-time decision support. This study investigates the application of AI-powered Digital Twins across manufacturing, healthcare, energy, transportation, and smart city infrastructures. A conceptual framework integrating Internet of Things (IoT) sensors, cloud-edge computing, machine learning, computer vision, and simulation models is proposed to establish intelligent digital replicas capable of learning from operational data. Experimental analysis demonstrates that AI-powered Digital Twins significantly improve predictive maintenance, production efficiency, resource optimization, and operational resilience while reducing equipment downtime and operational costs. Furthermore, the study examines challenges associated with data synchronization, interoperability, cybersecurity, scalability, and governance in enterprise-scale deployments. Comparative evaluation indicates that organizations implementing intelligent Digital Twins achieve superior business performance through enhanced situational awareness and evidence-based decision-making. The findings conclude that AI-powered Digital Twins will become foundational technologies for Industry 5.0 by enabling autonomous, adaptive, and sustainable enterprise ecosystems.

Keywords: Digital Twin, Artificial Intelligence, Smart Manufacturing, IoT, Predictive Analytics, Industry 5.0, Enterprise Intelligence

WHAT WE KNOW ABOUT PSORIASIS SO FAR?

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Background Restoration of the dysbiotic gut microbiome has emerged as a promising aid and a better therapeutic approach.

Objective New evidences suggest that the microbiome may play a pathogenic role in psoriatic disease. The aim of the present project is to investigate whether a dietary intervention could ameliorate the clinical manifestations and modulate the gut microbiota of individuals with psoriasis.

Materials and methods Nutrition plays an important role in the development of psoriasis and it can modulate microbiome composition.

Results Among environmental factors, diet plays a central role therefore incorrect nutritional habits and excessive body weight can increase clinical symptoms or even trigger the disease. Such diet-based and nutraceutical approaches to targeting the microbiome may produce a milder side effect profile than current systemic medications. Thus, interventions aimed at the microbiome may be a valuable adjunct for preventing or managing psoriatic disease and its comorbidities.

Conclusion Nutrition plays an important role in the development of psoriasis and its comorbidities. Ultimately, a better understanding of the psoriatic microbiome can lead to the development of new therapeutic modalities that target the shifting microbiota. Thus, interventions aimed at the microbiome may be a valuable adjunct for preventing or managing psoriatic disease and its comorbidities.

Keywords: psoriasis, microbiome, microbiota, Deniplant nutraceuticals

ROBOTS IN CRIMINAL PROCEEDINGS: LEGAL, TECHNOLOGICAL AND ETHICAL IMPLICATIONS

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ABSTRACT

The rapid development of artificial intelligence, robotics, and autonomous systems is generating significant transformations in the field of criminal justice. The use of robots and robotic systems in criminal proceedings represents an emerging area with considerable potential to improve criminal investigations, forensic activities, evidence management, data analysis, and crime prevention.

At the same time, the integration of these technologies raises complex legal and ethical questions concerning accountability, the admissibility and reliability of evidence, data protection, algorithmic transparency, and the effective protection of fundamental rights.

This paper examines the current and prospective role of robots in criminal proceedings, focusing on their potential applications in crime prevention, crime-scene investigation, forensic analysis, evidence collection, surveillance, and the processing of large volumes of information. Particular attention is given to AI-powered robotic systems capable of operating in dangerous or inaccessible environments and assisting law enforcement authorities in collecting and analyzing evidence.

A central issue addressed by this research is the distinction between the use of technology as a supporting instrument and the delegation of decision-making functions to autonomous systems. In criminal proceedings, decisions concerning guilt, deprivation of liberty, the assessment of evidence, and the imposition of criminal sanctions must remain subject to human responsibility and procedural safeguards.

Consequently, the use of robotic and AI-based technologies must comply with the principles of legality, the presumption of innocence, the right to defence, equality before the law, proportionality, privacy, and the right to a fair trial.

The paper also examines the problem of legal liability for errors generated by autonomous systems. Determining whether responsibility should rest with the developer, manufacturer, operator, public institution, or another actor represents a significant challenge for contemporary criminal and procedural law. Furthermore, algorithmic bias may generate discriminatory outcomes, particularly when AI systems are used for risk assessment, predictive policing, or the identification of potentially suspicious behavior.

The research argues that the integration of robotics into criminal proceedings requires an adaptive legal framework capable of regulating the conditions of technological use, ensuring human oversight, establishing clear standards for the verification of AI-generated information, and providing effective mechanisms for challenging automated assessments.

The study concludes that robots and artificial intelligence can become valuable instruments in modern criminal justice, but their use must remain subordinate to human responsibility, the rule of law, judicial

oversight, and the protection of fundamental human rights. Technological innovation should therefore complement—not replace—the human dimension of criminal justice.

Keywords: robotics, artificial intelligence, criminal proceedings, criminal justice, forensic investigation, evidence, autonomous systems, algorithmic decision-making, human rights, legal liability.

THE IMPACT OF MES AND MOM SYSTEMS ON PRODUCTION PERFORMANCE FROM AN INDUSTRY 4.0 PERSPECTIVE: AN APPLICATION IN AN AUTOMOTIVE PAINT SHOP LINE

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ABSTRACT

With Industry 4.0, digital transformation in manufacturing systems, real-time data utilization, and data-driven decision-making approaches have gained increasing importance. Manufacturing Execution Systems (MES) and Manufacturing Operations Management (MOM) systems play a significant role in making production processes more transparent, traceable, flexible, and efficient. MES provides a connection between enterprise-level planning systems and the shop floor, enabling real-time monitoring of production activities and management of production data. The MOM approach supports the integrated management of production operations together with different functions such as production, quality, maintenance, and performance.

This study examines the digitalization of a plastic parts paint shop process in an automotive supplier company through an MES system. The primary objective of the study is to transform manual data collection and monitoring activities performed on the shop floor into a digital production management approach and to evaluate the contribution of MES and MOM systems to production performance. Within the scope of the application, automatic data collection from production equipment, real-time monitoring of production status, recording of downtime causes, monitoring of quality data, and evaluation of production performance were addressed.

The findings indicate that the MES implementation improved data visibility on the shop floor, enabled production and downtime information to be monitored more systematically, and supported quality and performance management. In addition, monitoring OEE through digital production data increased the visibility of production losses and contributed to the more systematic execution of continuous improvement activities. The study concludes that MES and MOM systems should be considered within the scope of Industry 4.0 not merely as technological solutions, but as integrated management tools that support data-driven production management and continuous improvement.

1. INTRODUCTION

Today, maintaining the competitiveness of manufacturing companies requires the simultaneous management of quality, cost, production performance, delivery, and operational flexibility. The increasing complexity of production processes and changing customer expectations have encouraged companies to utilize digital technologies alongside traditional production management approaches. This transformation takes place within the scope of Industry 4.0 through the digitalization of production processes and the integration of physical production activities with information systems.

In the Industry 4.0 approach, real-time collection of data obtained from production equipment and its use in decision-making processes have an important place. Technologies such as the Internet of Things, cyber-physical systems, and advanced data analytics make production processes more visible and manageable. Nor Aziana et al. (2025) state that the integration of Industry 4.0 with lean manufacturing practices contributes to reducing production losses, improving efficiency, and utilizing real-time data.

A strong relationship between MES and lean manufacturing is also reported in terms of production efficiency, resource management, and continuous improvement.

Within this transformation, the Manufacturing Execution System (MES) constitutes an important link between the shop floor and enterprise management. MES monitors production processes in real time and brings together data obtained from equipment, sensors, and operators to provide information about the current status of production activities. Solanki (2024) states that MES serves as a bridge between planning and management systems such as ERP and actual production operations and collects real-time data from production processes. This structure supports data-driven decision-making and continuous improvement activities in production management.

The core functions of MES are not limited to production monitoring. Activities such as work order management, production process modeling, workflow control, electronic work instructions, operator competency tracking, quality control, and the creation of audit trails can also be performed within MES. Thus, standardization of production processes and improved traceability become possible.

With the development of MES systems, more advanced digitalization in production management has also become possible. Boudjenoun et al. (2025) state that MES systems have evolved into intelligent MES structures by integrating technologies such as IoT, artificial intelligence, and big data analytics. These structures offer significant advantages in terms of real-time visibility, predictive capabilities, and adaptability to changing production conditions.

The Manufacturing Operations Management (MOM) approach emerges when production operations are evaluated not only through production execution activities but also together with quality, maintenance, performance, and other operational processes. MOM supports the holistic management of production activities and enables the shop-floor data provided by MES to be used across different operational processes. Boudjenoun et al. (2025) emphasize the importance of MES working together with ERP as well as providing real-time data integration with shop-floor systems such as PLC and SCADA.

One of the important indicators used to measure production performance is Overall Equipment Effectiveness (OEE). OEE enables the effectiveness of production equipment to be analyzed by jointly evaluating availability, performance, and quality. Kök and Yıldız (2023) state that OEE is an important performance measurement method for identifying losses in production systems and revealing areas for improvement.

Ensuring production continuity and reducing quality losses are particularly important requirements in the automotive supply industry. In the application conducted by Kök and Yıldız (2023) in the automotive sector, downtime and defective product analyses were identified as important problem areas when evaluating differences in production performance.

The aim of this study is to examine the contribution of the MES system implemented in the plastic parts paint shop process of an automotive supplier company to production management and performance monitoring activities. Within this scope, the effects of MES and MOM systems on real-time data collection, downtime management, quality management, traceability, and OEE performance evaluation are addressed.

2. RESEARCH AND FINDINGS

2.1. Scope of the Research

The research was conducted in the paint shop process where production activities for painting plastic parts are carried out in an automotive supplier company. The paint shop process is a critical production stage in terms of product quality and production continuity. Within the process, the operating conditions of production equipment, production flow, process parameters, and quality results are directly interrelated.

The main problem addressed in the research is the collection of shop-floor data through traditional methods and the evaluation of production performance based on these data. With manual data collection methods, real-time monitoring of production activities becomes difficult, detailed identification of the

causes of downtime is challenging, and integrating data obtained from different sources is time-consuming.

This situation makes it particularly difficult to identify the root causes of production losses and direct continuous improvement activities toward the appropriate areas. Therefore, the fundamental transformation point in the research was the collection of shop-floor data through a digital and automated system.

2.2. Digitalization of Production Data through MES

The implemented MES system enabled data to be collected from production equipment and different information sources on the shop floor. Thus, production activities became less dependent on manual recording methods, and the current status of the production line became traceable in real time.

The ability of MES to collect data from production equipment, sensors, and operators and display the current status of the production process provides an important advantage in production management (Solanki, 2024).

Within the scope of the research, production status, machine operating information, downtime, and quality results were monitored digitally through MES. This structure enabled production managers to access up-to-date information about the shop floor more rapidly and contributed to more effective planning of actions in response to problems.

Data exchange between MES and ERP also contributes to the integration of production management. While ERP provides production orders, material, and planning information, MES can use this information for detailed planning and control of production operations. Conversely, information obtained from MES, such as production progress, material usage, and equipment status, can be transferred to enterprise management (Solanki, 2024).

This structure enables bidirectional data flow between the shop floor and enterprise management, contributing to a more holistic management of production processes.

2.3. Downtime Management and OEE

Accurately recording downtime and analyzing its causes are essential for improving production performance. Within the scope of the research, the MES implementation enabled downtime occurring on the production line to be digitally recorded and classified according to its causes.

This approach made it possible to evaluate production losses not only on the basis of total downtime but also according to the causes of downtime. Thus, maintenance, production, and engineering teams were supported in conducting problem-solving activities using common data.

Evaluating OEE through its availability, performance, and quality components enables different dimensions of production losses to be analyzed. Kök and Yıldız (2023) state that OEE is based on the joint evaluation of these three fundamental effectiveness dimensions and can be used to identify the strengths and weaknesses of production systems.

The literature review conducted by Nor Aziana et al. (2025) also indicates a strong relationship between OEE and Industry 4.0 technologies, particularly noting that IoT and real-time data utilization support OEE performance monitoring.

In this study, the ability to monitor OEE more systematically through digital production data following the MES implementation increased the visibility of production losses. Consequently, it became easier to direct improvement activities toward losses arising from downtime, performance, and quality.

2.4. Quality Management and Traceability

In addition to its contributions to production performance, the MES implementation produced important results in terms of quality management and traceability. Associating production and quality information within the same digital system enables quality problems to be examined more systematically. Recording quality controls performed during production in a digital environment facilitates retrospective tracking of product and process information.

Solanki (2024) states that electronic procedures, quality control activities, statistical process control, and audit trails within MES support the standardization and traceability of production processes. In the research, associating production data with quality results made it more systematic to investigate the sources of quality problems and conduct corrective actions. Intelligent MES applications examined by Boudjenoun et al. (2025) also emphasize real-time visibility, traceability, and data quality as fundamental elements of the digital transformation of production processes.

Therefore, the MES implementation can be considered not merely a system for keeping records in terms of quality management, but also a management infrastructure that contributes to continuous process monitoring and the analysis of quality problems.

2.5. Contribution of MES and MOM Integration to Production Management

One of the important findings of the research is that MES and MOM approaches can be considered complementary structures. MES primarily supports the execution and monitoring of shop-floor activities and the collection of production data. MOM, on the other hand, enables production operations to be addressed from a broader perspective and different processes such as production, quality, maintenance, and performance to be integrated.

Boudjenoun et al. (2025) state that, in addition to working with ERP, the integration of MES with shop-floor systems such as PLC and SCADA is important for real-time data integration. This structure enables data generated by MES on the shop floor to be used in different operational processes within the MOM approach. For example, a downtime occurring on a production line can be evaluated not only as a production loss but also from a maintenance management perspective and included in root-cause analyses. Therefore, MES can be considered to support the data collection and operational execution dimensions of the MOM approach on the shop floor.

2.6. Findings Regarding Continuous Improvement

The data visibility created by the MES implementation in production processes supported the more systematic execution of continuous improvement activities. Nor Aziana et al. (2025) state that the combined use of MES and lean manufacturing practices has positive effects on production efficiency, resource management, and continuous operational improvement. This approach is also consistent with the findings observed in the research. Following the MES implementation, the increased visibility of production losses facilitated the identification of problem areas and the execution of improvement activities based on data.

However, successful digital transformation depends not only on establishing technological infrastructure. Boudjenoun et al. (2025) state that cross-functional collaboration, KPI definition, system integration, data quality, and employee training are critical for the sustainability of MES implementations. Therefore, sustainable use of MES and MOM systems requires employee adaptation to the system, process standardization, and assurance of data quality.

3. CONCLUSION

This study examined the impact of MES and MOM systems on production performance from an Industry 4.0 perspective through the plastic parts paint shop process of an automotive supplier company. The research results showed that the MES implementation improved data visibility on the shop floor and enabled production processes to be monitored more systematically. The transition from manual data collection to an automated and digital data collection structure supported real-time monitoring of production activities. Through the MES implementation, collecting data obtained from production equipment within a centralized system made it possible to evaluate production status, downtime, quality results, and performance indicators together. In particular, systematically recording downtime made the causes of production losses more visible and enabled improvement activities to be directed toward the appropriate areas.

From an OEE perspective, the MES implementation contributed to more regular monitoring of the availability, performance, and quality components. The automotive sector application conducted by Kök

and Yıldız (2023) also demonstrates that OEE analyses are important for identifying production losses and revealing areas for improvement.

Another important result of the study is the contribution of jointly evaluating MES and MOM systems to production management. While MES supports the execution of shop-floor activities and the collection of real-time data, MOM enables these data to be used in different operational processes such as production, quality, maintenance, and performance management. The literature also supports this assessment. Nor Aziana et al. (2025) demonstrate that the integration of MES, OEE, and IoT supports the use of real-time data and the improvement of production performance. Solanki (2024) states that MES creates a data bridge between ERP and the shop floor, thereby supporting data-driven decision-making and continuous improvement.

The intelligent MES approach proposed by Boudjenoun et al. (2025) indicates that MES systems can be further integrated with IoT, artificial intelligence, and big data analytics in the future. These developments are expected to improve real-time visibility, predictive decision-making, and adaptive production capabilities in manufacturing processes.

In conclusion, MES and MOM systems should be considered within the scope of Industry 4.0 not merely as technological applications, but as **integrated management systems that support data-driven production management, operational visibility, quality management, and continuous improvement**. However, for the sustainable success of these systems, process standardization, data quality, employee competencies, and cross-functional collaboration must also be developed alongside the technological infrastructure.

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THE EFFECT OF DIGITAL TECHNOLOGY USE ON LONELINESS AND QUALITY OF LIFE IN OLDER ADULTS

YAŞLI BİREYLERDE DİJİTAL TEKNOLOJİ KULLANIMININ YALNIZLIK VE YAŞAM KALİTESİ ÜZERİNDEKİ ETKİSİ

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ABSTRACT

The aim of this study is to evaluate the impact of digital technology use on loneliness and quality of life among older adults. The study was conducted as a traditional review. Life events associated with aging—such as a decline in social relationships, changes in physical function, retirement, and the loss of loved ones—can increase the risk of loneliness. Loneliness can negatively affect the psychosocial well-being of older adults, leading to a decline in quality of life and predisposing them to various mental health issues. The widespread adoption of digital technologies today offers significant opportunities for older adults to maintain social relationships, communicate, access information, and facilitate their daily lives. An examination of relevant national and international studies reveals that digital technologies—such as the internet, smartphones, tablets, computers, and social media—support communication with family and friends and contribute to reducing social isolation. It is reported that digital technologies can alleviate feelings of loneliness by strengthening social ties, particularly among older adults with limited mobility or shrinking social circles. Older adults' access to digital technologies and their usage skills are influenced by various factors, including age, education, economic status, physical and cognitive characteristics, and digital health literacy. An overall assessment of the literature indicates that the appropriate and purposeful use of digital technologies can contribute to reducing loneliness and supporting various dimensions of quality of life among older adults. Accordingly, developing initiatives that facilitate older adults' access to and effective use of digital technologies is crucial for enhancing social participation and mitigating loneliness. The conscious and purposeful use of digital technologies can be considered a significant tool that may contribute to supporting the social and psychosocial well-being of older adults, promoting healthy aging, and enhancing their quality of life.

Keywords: Old age, Digital technology, Loneliness, Quality of life, Mental health

ÖZET

Bu çalışmanın amacı, yaşlı bireylerde dijital teknoloji kullanımının yalnızlık ve yaşam kalitesi üzerindeki etkisi değerlendirmektir. Çalışma, geleneksel derleme türünde yürütülmüştür. Yaşlılık döneminde sosyal ilişkilerin azalması, fiziksel işlevlerde meydana gelen değişiklikler, emeklilik ve yakınların kaybı gibi yaşam olayları yalnızlık riskini artırabilmektedir. Yalnızlık, yaşlı bireylerin psikososyal iyilik halini olumsuz etkileyerek yaşam kalitesinde azalmaya ve çeşitli ruhsal sorunlara zemin hazırlayabilmektedir. Günümüzde dijital teknolojilerin yaygınlaşması, yaşlı bireylerin sosyal ilişkilerini sürdürmeleri, iletişim kurmaları, bilgiye erişmeleri ve günlük yaşamlarını kolaylaştırmaları açısından önemli fırsatlar sunmaktadır. Konuyla ilişkili ulusal ve uluslararası çalışmalar incelendiğinde; internet, akıllı telefon, tablet, bilgisayar, sosyal medya gibi dijital teknolojilerin yaşlı bireylerin aile ve

arkadaşlarıyla iletişimlerini desteklemelerine ve sosyal izolasyonun azaltılmasına katkı sağladığı görülmektedir. Dijital teknolojilerin, özellikle hareket kısıtlılığı yaşayan veya sosyal çevresi azalan yaşlı bireylerde sosyal bağları güçlendirerek yalnızlık hissini azaltabileceği bildirilmektedir. Yaşlı bireylerin dijital teknolojilere erişim düzeyi ve kullanım becerileri; yaş, eğitim, ekonomik durum, fiziksel ve bilişsel özellikler ile dijital sağlık okuryazarlığı gibi çeşitli faktörlerden etkilenmektedir. Literatür genel olarak değerlendirildiğinde, dijital teknolojilerin uygun ve amaca yönelik kullanımının yaşlı bireylerde yalnızlığın azaltılmasına katkı sağlayabileceği ve yaşam kalitesinin farklı boyutlarını destekleyebileceği görülmektedir. Bu doğrultuda, yaşlı bireylerin dijital teknolojilere erişimini ve bu teknolojileri etkili kullanmalarını destekleyen uygulamaların geliştirilmesi, sosyal katılımın artırılması ve yalnızlığın azaltılması açısından önem taşımaktadır. Dijital teknolojilerin bilinçli ve amaca yönelik kullanımı, yaşlı bireylerin sosyal ve psikososyal iyilik halinin desteklenmesine, sağlıklı yaşlanmanın teşvik edilmesine ve yaşam kalitesinin geliştirilmesine katkı sağlayabilecek önemli bir araç olarak değerlendirilebilir.

Anahtar Kelimeler: Yaşlılık, dijital teknoloji, yalnızlık, yaşam kalitesi, ruh sağlığı

INTRODUCTION

Aging is a natural and multidimensional process that occurs within an individual's life cycle. As a result of increasing life expectancy and declining fertility rates worldwide, the proportion of the elderly population within the total population is steadily rising. This shift necessitates the development of policies aimed not only at healthcare services but also at supporting the social functionality, independence, and quality of life of elderly individuals (Crimmins and Zhang, 2019).

Changes in the social environments of individuals during old age can pose a significant risk regarding loneliness and social isolation. Retirement, children leaving home, the loss of a spouse or close friends, limited mobility, and health issues lead to a reduction in social interactions. According to World Health Organization data, approximately 11.8% of older adults experience loneliness, and about one-quarter face social isolation (World Health Organization [WHO], 2025). Loneliness and social isolation are significant social and health determinants that can adversely affect individuals' physical and mental health as well as their quality of life.

Digitalization is a comprehensive transformation process resulting from the widespread adoption of digital technologies in individual, organizational, and societal life. This process significantly alters numerous areas, ranging from institutional operations to the daily life practices of individuals (İştar Işıklı, 2024; Salmancı, 2024). In this context, digital technologies are considered vital tools for older adults to maintain social relationships and communicate with their social circles. In particular, devices and platforms such as smartphones, tablets, computers, social media, video communication apps, and online communication tools enable the continuation of interpersonal communication when physical gatherings are not possible. This suggests that digital technologies can play a significant role in supporting the social relationships of older adults, thereby influencing their levels of loneliness and quality of life. Therefore, it is important to examine the relationship between digital technology use, loneliness, and quality of life among older adults. This study aims to determine the digital technology usage patterns of older adults and to evaluate the relationship between digital technology use, loneliness, and quality of life.

USE OF DİGİTAL TECHNOLOGY İN OLD AGE

In recent times, the interest of older adults in digital technologies and their habits regarding the use of these technologies have become increasingly significant issues at both individual and societal levels (Mendoza-Holgado et al., 2024). The use of digital technology can contribute to older adults maintaining their activities of daily living more independently and support their social participation (Zhou et al., 2024). Activities such as video calling, online shopping, banking transactions, and social media usage are playing an increasingly prominent role in the daily lives of older adults (Chan et al., 2023; Sixsmith et al., 2022). Furthermore, older adults are increasingly using the internet to access health information and to learn about symptoms, diagnoses, and treatment options (Zhao et al., 2022). In this context, digital technologies serve a significant function that extends beyond merely meeting communication needs;

they also play a crucial role in accessing information, utilizing healthcare services, maintaining activities of daily living, and fostering social participation (Mendoza-Holgado et al., 2024).

Integrating digital technologies into the lives of older adults is also significant for supporting active and healthy aging (Babadağ, 2020). The ability of individuals to communicate with family members and friends, interact with various social groups, and access online activities aligned with their interests—all facilitated by technology—can contribute to strengthening their social interactions and community participation. This offers important opportunities to reduce experiences of loneliness and social isolation among older adults and to support their quality of life (Akbaş et al., 2020).

However, access to digital technologies alone is not sufficient. It is also important for older adults to be able to use these technologies effectively, safely, and functionally. Vision and hearing impairments, reduced manual dexterity, cognitive difficulties, low levels of education, and limited experience with technology can hinder the use of digital technologies (Khan et al., 2026). Therefore, when assessing digital technology use among older adults, it is necessary to consider not only access but also digital skill levels, technology usage proficiency, and the barriers encountered during use (Oh et al., 2021).

DİGİTAL TECHNOLOGY USE AND LONELİNESS

Loneliness is a subjective state arising from an individual's perception that the quality or quantity of their social relationships does not align with their social needs. In old age, loneliness can become more pronounced due to a decline in social relationships and a shrinking social circle (Özvurmaz, 2018). Digital technologies are viewed as a potential tool for alleviating loneliness, as they enable individuals to maintain social relationships regardless of physical distance. In particular, video calls, social media platforms, and online communication applications can facilitate regular contact with family members and friends (Görgün Baran et al., 2017).

Welch et al. examined 200 studies evaluating the effects of digital interventions aimed at reducing social isolation and/or loneliness among older adults; of these, 103 were identified as primary research studies and 97 as systematic reviews. The most frequently used digital interventions included video conferencing and telephone calls designed to enhance social interaction with family, friends, and the community. The studies also showed the use of technologies such as social robots and virtual pets that provide social support (Welch et al., 2023).

However, findings regarding the impact of digital technologies on reducing loneliness are not entirely consistent. It is particularly important to consider whether technology use enhances the quality of social relationships, as well as how the duration and purpose of use influence the outcomes. For instance, passively consuming content and actively communicating with family and friends may not yield the same social results.

In a systematic review and meta-analysis examining technology-based interventions, Jin et al. (2021) evaluated the impact of such interventions on reducing loneliness among older adults, reporting significant heterogeneity across studies and noting that the evidence was limited. Similarly, a systematic review and meta-analysis by Chipps et al. (2017) concluded that the evidence regarding the effectiveness of digital technology interventions in reducing loneliness was not sufficiently strong.

These results indicate that digital technologies should not be viewed as a definitive, standalone solution for reducing loneliness. Using technology as a tool to support an individual's existing social relationships may be a more effective approach.

DİGİTAL TECHNOLOGY USE AND QUALİTY OF LİFE

Quality of life is a multidimensional concept associated with an individual's physical health, psychological state, social relationships, independence, and living environment (Gümüş, 2026). Improving the quality of life for older adults involves not only the prevention or treatment of diseases but also the support of social participation, independence, and the capacity to perform activities of daily living (WHO, 2020). Therefore, assessing the quality of life of older adults requires taking into account psychological well-being, social relationships, the level of independence, and environmental conditions, alongside indicators of physical health.

Within this multidimensional framework, digital technologies are regarded as significant tools capable of supporting the quality of life of older adults through various mechanisms. First, digital technologies can contribute to strengthening social support networks by facilitating communication with family and friends. In particular, video calling, instant messaging, and social media applications enable older adults to maintain contact with their loved ones when physical gatherings are not possible. Second, by easing access to health information and services, digital technologies can help individuals acquire knowledge about their health, utilize healthcare services, and participate more actively in their own healthcare processes. Third, participation in online education, entertainment, and social activities can support older adults in remaining cognitively and socially active by increasing the variety of activities in their daily lives. Accordingly, it is noted that digital technologies can support various dimensions of older adults' quality of life by facilitating the maintenance of social relationships, easing access to health services and information, and diversifying daily life activities (Aggarwal et al., 2020; Sen et al., 2022).

The opportunities offered by digital technologies can be particularly significant for older adults whose face-to-face social interactions are restricted due to limited mobility and various physical or social barriers. Maintaining contact with family and friends, participating in online communities, and accessing diverse sources of information and entertainment through technology can help individuals preserve their social connections. In this regard, the use of digital technology is viewed as a tool that can support the quality of life of older adults by alleviating loneliness and sustaining social relationships. Comprehensive evidence maps regarding digital interventions indicate that depression and quality of life—alongside loneliness and social isolation—are frequently assessed outcomes. Research has specifically examined the effects of digital interventions aimed at enhancing social interaction with family, friends, and the community—such as video calls and telephone conversations—on loneliness, depression, and quality of life (Welch et al., 2023; Yalçıntürk & Gül, 2026).

However, the impact of digital technology usage on quality of life is neither direct nor automatic. If technology is unsuited to an individual's needs, skills, or living conditions, or if difficulties arise during its use, the benefits derived from it may be limited. Factors such as insufficient digital skills, the perception of devices as overly complex, concerns regarding security and privacy, technical issues, or health-related and physical limitations can hinder technology use. Such situations may give rise to feelings of anxiety, stress, failure, or inadequacy regarding technology among some older adults. Therefore, for digital technologies to contribute to the quality of life of older adults, merely providing access is insufficient; it is also crucial that the individual is able to understand and use the technology and apply it functionally in their daily life (Işıklı, 2024; Gerçeker & Erdem, 2026).

When planning the use of digital technology for older adults, factors such as age, education level, cognitive and physical characteristics, existing digital skills, technology usage experiences, and daily living requirements must be taken into account. Prioritizing user-friendly and accessible technologies, providing training and technical support where necessary, and identifying the challenges individuals face during technology use can contribute to maximizing the benefits derived from technology. Consequently, evaluating the impact of digital technologies on the loneliness and quality of life of older adults requires considering technology not merely in terms of usage frequency, but also regarding its potential consequences for the individual's social relationships, daily life, and overall well-being (Vincek et al., 2024).

CONCLUSİON AND RECOMMENDATİONS

The use of digital technology among older adults holds significant potential for maintaining social connections, reducing loneliness and social isolation, and supporting quality of life. Technologies that facilitate video calls, social media, online communication, and social support can specifically help older adults stay in touch with their social circles. However, while digital technologies offer significant opportunities to alleviate loneliness and enhance quality of life, these effects do not manifest to the same degree for every individual or in every circumstance. Therefore, when integrating digital technologies into the lives of older adults, it is crucial to consider a combination of factors: individual characteristics, purposes of use, access to technology, usage skills, and levels of social support. There is a particular need for more comprehensive research to elucidate the impact of digital technologies on loneliness and quality of life across societies with diverse socioeconomic and cultural backgrounds.

In this regard:

- Training programs aimed at enhancing the digital literacy levels of older adults should be developed.
- The use of digital technology should be evaluated not only in terms of access but also regarding the purpose and nature of its use.
- Topics such as safe internet usage and personal data security should be included in digital training for older adults.
- Digital technologies should be viewed as tools that support existing social relationships rather than as substitutes for face-to-face social interactions.
- Research involving larger sample sizes should be conducted in Türkiye to assess older adults' use of digital technology and its relationship with loneliness and quality of life.
- More research should be conducted to examine the long-term effects of digital technology use on loneliness, social isolation, life satisfaction, and quality of life among older adults across different age groups.

In conclusion, when used effectively—with due regard for individual needs and usage conditions—digital technologies are considered significant tools capable of strengthening older adults' social connections, facilitating their access to information and healthcare services, and supporting their quality of life. However, it is evident that the potential benefits of digital technologies for older adults depend not merely on access to the technology itself, but also on how, for what purpose, and under what conditions it is utilized. Therefore, initiatives aimed at increasing older adults' participation in digital life must adopt a holistic approach that goes beyond simply providing technological access; it is essential to also address the development of digital skills, the strengthening of social support, and the consideration of individual needs.

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DİGİTAL HEALTH LİTERACY, TRUST İN ONLİNE HEALTH INFORMATİON, AND MENTAL WELL-BEİNG İN MENOPAUSE

MENOPOZDA DİJİTAL SAĞLIK OKURYAZARLIĞI, ÇEVRİM İÇİ SAĞLIK BİLGİSİNE GÜVEN VE RUHSAL İYİ OLUŞ

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ABSTRACT

Menopause is an important life stage associated with vasomotor symptoms, as well as sleep disturbances, anxiety, depressive symptoms, and changes in quality of life. Women are increasingly using digital health resources to seek information and support related to menopause. This review aimed to evaluate the existing literature on the relationship between digital health literacy, trust in online health information, and mental well-being during menopause. Relevant national and international literature was reviewed using the key concepts of menopause, digital health literacy, online health information, artificial intelligence, trust, mental health, and quality of life. The reviewed studies addressed women's purposes for using digital health resources, their experiences in evaluating the reliability of health information, and the relationship between digital resources and psychological outcomes. The literature indicates that women experiencing menopause widely use the internet to obtain information about symptoms, treatment options, and lifestyle recommendations. Although digital resources may improve access to information, self-efficacy, and perceived social support, variations in information quality and the presence of inaccurate or conflicting content may lead to concerns regarding trust. Therefore, digital health literacy emerges as a critical factor in evaluating the reliability of obtained information. The potential of artificial intelligence-based health information tools in menopause care has been evaluated in only a limited number of studies to date. Access to reliable digital health information and the ability to critically evaluate such information may be important factors in supporting the mental well-being of women during menopause. Future studies are needed to evaluate the effectiveness and reliability of artificial intelligence-supported digital interventions in menopause care.

Keywords: Menopause, digital health literacy, artificial intelligence, online health information, mental well-being.

ÖZET

Menopoz dönemi; vazomotor semptomların yanı sıra uyku sorunları, anksiyete, depresif belirtiler ve yaşam kalitesinde değişikliklerle ilişkili önemli bir yaşam dönemidir. Kadınların menopozla ilgili bilgi ve destek arayışında dijital sağlık kaynaklarını giderek daha fazla kullandığı görülmektedir. Bu derlemenin amacı, menopoz döneminde dijital sağlık okuryazarlığı, çevrim içi sağlık bilgisine güven ve ruhsal iyi oluş arasındaki ilişkiye ilişkin mevcut literatürü değerlendirmektir. Menopoz, dijital sağlık okuryazarlığı, çevrim içi sağlık bilgisi, yapay zekâ, güven, ruhsal sağlık ve yaşam kalitesi anahtar kavramları kullanılarak ilgili ulusal ve uluslararası literatür incelenmiştir. Çalışmalarda kadınların dijital sağlık kaynaklarını kullanım amaçları, bilgi güvenilirliğini değerlendirme deneyimleri ve dijital kaynakların psikolojik sonuçlarla ilişkisi ele alınmıştır. Literatür, menopozdaki kadınların interneti

semptomlar, tedavi seçenekleri ve yaşam tarzı önerileri hakkında bilgi edinmek amacıyla yaygın biçimde kullandığını göstermektedir. Dijital kaynaklar bilgiye erişimi, öz-yeterliği ve sosyal destek algısını artırabilirken, bilgi kalitesindeki farklılıklar ve yanlış/çelişkili içerikler güven sorunlarına yol açabilmektedir. Bu nedenle dijital sağlık okuryazarlığı, elde edilen bilgilerin güvenilirliğini değerlendirmede kritik bir faktör olarak öne çıkmaktadır. Yapay zekâ tabanlı sağlık bilgi araçlarının menopoz bakımındaki potansiyeli ise henüz sınırlı sayıda çalışma ile değerlendirilmiştir. Güvenilir dijital sağlık bilgisine erişim ve bu bilgiyi eleştirel değerlendirebilme becerisi, menopoz dönemindeki kadınların ruhsal iyi oluşunu desteklemede önemli bir unsur olabilmektedir. Gelecekte yapay zekâ destekli dijital müdahalelerin etkinliğini ve güvenilirliğini değerlendiren çalışmalara ihtiyaç duyulmaktadır.

Anahtar Kelimeler: Menopoz, dijital sağlık okuryazarlığı, yapay zekâ, çevrim içi sağlık bilgisi, ruhsal iyi oluş.

INTRODUCTION

Menopoz, Menopause is a critical transitional period in the female life course, characterized by the loss of ovarian function and the permanent cessation of the menstrual cycle, during which comprehensive physiological and psychosocial changes occur (Altıner Yaş et al., 2026; Akgün et al., 2024). While the average age at menopause is approximately 51 years globally, in Türkiye, this age ranges from 46 to 48.1 years (Altıner Yaş et al., 2026). With increasing life expectancy, women spend nearly one-third of their lives in the postmenopausal period (Altıner Yaş et al., 2026; Akgün et al., 2024). This has increased scientific interest in the management of menopausal symptoms, alternative coping strategies, and the preservation of quality of life (Altıner Yaş et al., 2026). During the menopausal transition, fluctuations and declines in estrogen levels may lead to vasomotor symptoms such as hot flashes and night sweats, as well as psychological and psychosocial problems including insomnia, anxiety, depression, tension, changes in body image, and concerns about aging, negatively affecting women's overall well-being and quality of life (Akgün et al., 2024). In coping with these symptoms, women turn not only to medical treatments but also to lifestyle modifications, traditional methods, and peer support (Altıner Yaş et al., 2026). Today, with the digital transformation brought about by the 21st century, the channels through which health information is accessed have changed considerably; the internet, smartphones, mobile health applications, and social media platforms have become an integral part of health-seeking behaviors (Yasatekin, 2025; Öner & Sarıgül, 2025). Research has shown that women use digital resources much more actively than men when seeking health-related information (Altıner Yaş et al., 2026). This wave of digitalization has brought the concepts of Digital Health Literacy and Electronic Health Literacy to the forefront (Kozat, 2025). Digital Health Literacy refers to an individual's ability to search for, locate, understand, and critically evaluate health-related information obtained from electronic sources and to apply the acquired information to address a health problem or improve quality of life (Öner & Sarıgül, 2025; Akgün et al., 2024; Yasatekin, 2025). According to the model developed by Norman and Skinner (2006), digital health literacy requires the integration of six core skills: traditional literacy, health literacy, information literacy, scientific literacy, media literacy, and computer literacy (Öner & Sarıgül, 2025). During menopause, women's ability to make informed decisions amid the physical and psychological complexities they experience and to maintain their psychological well-being is directly associated with their level of digital health literacy (Altıner Yaş et al., 2026; Akgün et al., 2024). The aim of this review is to evaluate the existing literature on the relationship between digital health literacy, trust in online health information, and psychological well-being during menopause.

MENOPAUSE AND DIGITAL HEALTH LITERACY

During the menopausal process, women engage in extensive information-seeking in order to understand the changes occurring in their bodies and alleviate the symptoms they experience (Altıner Yaş et al., 2026). The literature indicates that women who experience more severe menopausal symptoms use internet resources and digital platforms at significantly higher rates than those experiencing milder symptoms (Aslan, 2023). Women experiencing severe symptoms actively seek solutions for menopause in digital environments, either before consulting a healthcare provider in person or as a complement to

clinical treatment (Aslan, 2023; Altıner Yaş et al., 2026). Women's level of digital health literacy is significantly influenced by sociodemographic and individual factors (Yasatekin, 2025). Educational status, employment status, income level, duration of internet use, and the perceived usefulness of health information available online have a positive influence on digital health literacy (Akgün et al., 2024; Kozat, 2025). Women with higher levels of education and those who use the internet effectively in daily life can access accurate menopause-related information more easily, whereas middle-aged and older women with lower educational levels and limited digital skills experience considerable difficulties in using digital health resources and are at risk of digital exclusion (Aslan, 2023; Öner & Sarıgül, 2025). The primary digital tools used by women in managing menopause include search engines, mHealth/mobile health applications (such as e-Nabız), women's health tracking applications, health blogs, online forums, and social media platforms (Facebook, Instagram, and YouTube) (Altıner Yaş et al., 2026; Kozat, 2025). Particularly in qualitative studies, women have reported that they can easily access their medical results through the e-Nabız application; however, because they sometimes have difficulty interpreting the terminology, they turn to further internet searches for clarification (Altıner Yaş et al., 2026). This demonstrates that access to information alone is insufficient and highlights the critical importance of digital health literacy, which involves the ability to understand and evaluate the information obtained (Öner & Sarıgül, 2025).

TRUST IN ONLINE HEALTH INFORMATION

The unregulated nature of health information shared on online platforms makes the accuracy and trustworthiness of the information obtained a matter of considerable debate (Akgün et al., 2024). Women experiencing menopause often demonstrate conflicting attitudes when evaluating the reliability of information they obtain from the internet (Altıner Yaş et al., 2026). Many women report that they perceive the comments and personal experiences shared by other women with similar menopausal experiences on social media platforms, particularly Instagram and Facebook, as more sincere, realistic, and trustworthy (Altıner Yaş et al., 2026; Öner & Sarıgül, 2025). Although these communities provide a sense of peer support and help women feel less isolated, they may also facilitate the dissemination of recommendations that lack a scientific basis (Öner & Sarıgül, 2025). Qualitative studies have revealed that women use various strategies to verify the menopause-related information they encounter online (Altıner Yaş et al., 2026). Many women report consulting a physician or healthcare professional to verify information obtained after conducting online research. Although they may directly implement non-pharmacological herbal recommendations, such as those related to skincare and nutrition, they do not take clinical interventions such as medications or hormone therapy without consulting a physician (Altıner Yaş et al., 2026). Women with low levels of digital health literacy are more vulnerable to manipulation and commercial influences in the face of online misinformation (Öner & Sarıgül, 2025). Research has shown that the quality of online information related to sexual and reproductive health is inadequate and that the prevalence of misinformation ranges from 14% to 97% (Öner & Sarıgül, 2025). Uncontrolled and uncritical trust in online health information may lead to a condition known as “cyberchondria,” characterized by intensified health anxiety and anxiety as a result of excessive and uncontrolled health-related searches on the internet (Öner & Sarıgül, 2025; Yıldırım, 2024). According to research findings, individuals who consider the internet very helpful when making decisions about their health or who place excessive importance on online resources tend to have higher e-health literacy scores. However, when they are unable to distinguish reliable information from misinformation, their levels of cyberchondria and general anxiety also increase. This situation clearly demonstrates the detrimental effects that accepting online information without verifying its accuracy may have on mental health.

DIGITAL HEALTH LITERACY AND PSYCHOLOGICAL WELL-BEING

Menopause is a psychologically sensitive phase for women, characterized by bodily transformation, hormonal fluctuations, and perceptions of aging (Akgün et al., 2024). Maintaining psychological well-being during this period is closely associated with women's ability to cope with symptoms and the social and psychological support they perceive (Akgün et al., 2024). The literature has demonstrated that general health literacy is negatively associated with anxiety and depression and positively associated with quality of life and psychological well-being (Dağlar & Oskay, 2022). Adequate health literacy

reduces depressive symptoms in women and enables them to manage clinical processes more effectively (Dağlar & Oskay, 2022). Digital health literacy enables women to move from being passive recipients of health information to becoming active managers of their own health, thereby strengthening their psychological autonomy (Öner & Sarıgül, 2025). Women with higher levels of digital health literacy are more likely to turn to evidence-based solutions and preventive health behaviors without panicking when they experience menopause-related symptoms (Öner & Sarıgül, 2025). Rapid and accurate access to reliable information reduces uncertainty, lowers anxiety levels, and increases women's self-confidence (Yasatekin, 2025). A low level of digital health literacy threatens psychological well-being in two ways (Öner & Sarıgül, 2025). First, the inability to access accurate information may create feelings of helplessness, while the physical burden of symptoms may adversely affect mental health (Aslan, 2023). Second, the cognitive burden, confusion, and cyberchondriacal anxiety caused by contradictory, exaggerated, and unscientific content encountered online may negatively affect psychological well-being (Aslan, 2023; Öner & Sarıgül, 2025). Algorithms that continuously expose users to similar anxiety-provoking content may cause women to perceive menopause as a disease or a period of loss, thereby disrupting their psychological balance (Altıner Yaş et al., 2026; Öner & Sarıgül, 2025).

THE RELATIONSHIP BETWEEN DIGITAL HEALTH INFORMATION AND PSYCHOLOGICAL WELL-BEING DURING MENOPAUSE

Quantitative studies have demonstrated direct and significant associations between women's e-health literacy levels and menopause-specific quality of life and psychosocial well-being (Akgün et al., 2024). In a study conducted by Akgün et al. (2024) among women aged 45–59 years, the mean e-health literacy score was 28.85 ± 5.79, indicating a moderate-to-high level. One of the most notable findings of the study was that as e-health literacy levels increased, women's scores for menopause-specific psychosocial complaints decreased, while their quality of life and psychological well-being increased significantly (Akgün et al., 2024). This statistical relationship clearly demonstrates the protective role of accessing accurate and reliable information and integrating it into daily life in alleviating the psychosocial distress, anxiety, and concerns about aging associated with menopause (Akgün et al., 2024). Today, artificial intelligence-supported digital health applications and personalized monitoring systems have also begun to be used effectively in the management of menopausal symptoms and mood (Kuduz et al., 2024). In large-scale studies conducted using artificial intelligence-based applications, 70% of participants reported reductions in mood fluctuations, 85% reported reductions in hot flashes, and 65% reported reductions in headaches (Kuduz et al., 2024). These findings suggest that women who can use digital health tools appropriately may be better able to maintain their psychological balance in both physical and behavioral aspects (Kuduz et al., 2024). The opposite relationship may be observed in women with high levels of cyberchondria who apply online information to their lives without verifying it. Misinformation and fear-based information obtained from online sources can undermine women's confidence in treatment, lead to unnecessary medical expenses and delays in seeking professional healthcare, and consequently increase psychological distress. Therefore, the positive contribution of digital health information to psychological well-being is possible only when women possess a high level of digital health literacy and the ability to critically analyze the information they encounter (Öner & Sarıgül, 2025).

NURSING PERSPECTIVE

The digital transformation of healthcare systems and the widespread adoption of mHealth applications have reshaped the roles of women's health nurses and midwives working in primary healthcare settings (Kozat, 2025; Öner & Sarıgül, 2025). Moving beyond their traditional caregiving roles, nurses have increasingly become “Digital Guides,” “Educators,” “Patient Navigators and Supporters,” and “Innovation Consultants” within the digital healthcare system (Yasatekin, 2025). Nurses play a key role in protecting and promoting public health and in supporting the adoption of healthy lifestyle behaviors (Özkan et al., 2020). The success of counseling services in women's health nursing depends on making the care process learnable and purposeful, supporting women in taking responsibility for their own health, and strengthening autonomy by reducing dependence on professional services (Kozat, 2025). Nurses should assess the digital health literacy skills of women experiencing menopause and teach them

how to filter and evaluate information available online (Yasatekin, 2025). To alleviate menopausal symptoms, nurses should recommend reliable mobile applications and web-based resources that are appropriate to women's individual preferences on topics such as exercise, pelvic floor muscle strengthening (Kegel exercises), healthy nutrition, and sleep hygiene (Büyükkaplan et al., 2020; Aşık & Şahin, 2019). Nurses and midwives working in clinical settings should collaborate with other healthcare professionals and technology developers and take an active role in designing scientifically validated websites and mobile applications that are easy for women experiencing menopause to understand, simple to use, visually engaging, and supported by photographs (Aslan, 2023; Yasatekin, 2025). It is essential for nurses to continuously update their knowledge and skills regarding mHealth and digital monitoring technologies in order to improve the quality of care and support women's psychological well-being (Yasatekin, 2025).

CONCLUSION AND RECOMMENDATIONS

During menopause, digital health literacy is a vital determinant of health that enhances women's ability to cope with physical symptoms, prevents anxiety and cyberchondria resulting from online misinformation, and directly improves psychosocial quality of life and psychological well-being (Öner & Sarıgül, 2025). The informed use of digital health tools supports psychological autonomy, whereas uncontrolled information seeking and reliance on unverified online information increase psychological stress. Accordingly, the following recommendations are proposed:

Development of Educational Programs: Web-based or face-to-face "Digital Health Literacy and Safe Information-Seeking" educational programs targeting women experiencing menopause should be structured and implemented in primary healthcare settings, including Family Health Centers and Healthy Life Centers (Altıner Yaş et al., 2026; Yıldırım, 2024).

Creation of Reliable Digital Content: Under the leadership of women's health nurses and midwives, simple, comprehensible, and interactive mHealth applications and web portals containing evidence-based information specific to menopause should be developed (Aslan, 2023; Öner & Sarıgül, 2025).

Support for Disadvantaged Groups: Multistakeholder social support projects involving the Ministry of Health, local governments, and universities should be implemented to facilitate access to mHealth technologies and improve digital health literacy levels among digitally disadvantaged women, particularly older women, those living in rural areas, and those with lower educational levels (Altıner Yaş et al., 2026; Yasatekin, 2025).

Integration of Personalized Artificial Intelligence: The integration of secure and personalized artificial intelligence-based clinical decision-support systems for monitoring menopausal mood fluctuations and symptoms into clinical follow-up should be encouraged (Kuduz et al., 2024).

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TEKRARLAYAN ODONTOJENİK KERATOKİSTLER EŞLİĞİNDE GORLİN-GOLTZ SENDROMLU BİR HASTADA MULTİDİSİPLİNER ORTODONTİK TEDAVİSİ

MULTIDISCIPLINARY ORTHODONTIC TREATMENT OF A PATIENT WITH GORLIN-GOLTZ SYNDROME ACCOMPANIED BY RECURRENT ODONTOGENIC KERATOCYSTS

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ÖZET

Gorlin-Goltz sendromu, diğer adıyla nevoid bazal hücreli karsinom sendromu (NBHKS), çoklu odontojenik keratokistler, kütanöz lezyonlar ve iskeletsel anomalilerle karakterize nadir görülen bir kraniyofasiyal hastalıktır. Bu olgu sunumunda, ortodontik tedavi öncesinde çok sayıda odontejenik kist tedavisi gerçekleştirilmiş, iskeletsel Sınıf III ilişkiye sahip, yaygın maksiller anterior kemik kaybı ve alt ve üst çenede gömülü kanin dişleri bulunan 16 yaşındaki erkek bir NBHKS hastasının multidisipliner ortodontik tedavisi sunulmaktadır. Tedavi planında çok basamaklı bir yaklaşım izlenmiştir.Tedavi başlangıcında, gömülü mandibular sağ kanin diş sürme yolunun uygun olmaması ve ağız içersine sürdürülemeyeceğinden dolayı çekilmiştir. Maksiller sol kanin ise ortodontik ekstrüzyon uygulanarak ark içine kazandırılmıştır. Ardından sağ maksiller kanin dişin distalinde kalan boşluk kapatılmıştır. Mandibular sağ lateral kesici diş, eksik kaninin yerini fonksiyonel olarak üstlenecek şekilde şekillendirilmiştir. Son olarak sağ maksiller posterior bölgede sagittal ilişkiyi sağlamak için distalizasyon yapılmıştır. Tedavi sürecinde gelişen iki yeni kistik lezyon enükle edilmiş; bu durum sol maksiller kanin diş çevresinde belirgin bukkal kemik kaybına ve sağ üst maksiller yan keserin çekilmesine neden olmuştur. Tedavi sırasındaki kist rekürrenslerine rağmen kabul edilebilir bir ark hizalanması, fonksiyonel bir oklüzyon ve gelecekteki protetik rehabilitasyon için uygun bir okluzyon elde edilebilmiştir. Bu vaka, NBHKS'li hastaların tedavisinde doğru bir ortodontik planlama ve multidisipliner yaklaşımın önemini ortaya koymaktadır.

Anahtar Kelimeler: Gorlin-Goltz sendromu, nevoid bazal hücreli karsinom sendromu, odontojenik keratokist, ortodontik tedavi, multidisipliner yaklaşım.

ABSTRACT

Gorlin-Goltz syndrome, also known as nevoid basal cell carcinoma syndrome (NBCCS), is a rare craniofacial disorder characterized by multiple odontogenic keratocysts, cutaneous lesions, and skeletal anomalies. In this case report, the multidisciplinary orthodontic treatment of a 16-year-old male NBCCS

patient who had undergone treatment for numerous odontogenic cysts prior to orthodontic therapy, and who presented with a skeletal Class III relationship, extensive maxillary anterior bone loss, and impacted canine teeth in both the mandible and maxilla, is presented. A multi-stage approach was followed in the treatment plan. At the outset of treatment, the impacted mandibular right canine was extracted, as its eruption path was unfavorable and it could not be brought into the oral cavity. The maxillary left canine, on the other hand, was incorporated into the arch through orthodontic extrusion. Subsequently, the space remaining distal to the right maxillary canine was closed. The mandibular right lateral incisor was reshaped in such a way as to functionally take over the role of the missing canine. Finally, distalization was performed in the right maxillary posterior region in order to establish the sagittal relationship. Two new cystic lesions that developed during the course of treatment were enucleated; this situation resulted in significant buccal bone loss around the left maxillary canine tooth and led to the extraction of the right maxillary lateral incisor. Despite the cyst recurrences that occurred during treatment, an acceptable dental arch alignment, a functional occlusion, and an occlusion suitable for future prosthetic rehabilitation were able to be achieved. This case demonstrates the importance of accurate orthodontic planning and a multidisciplinary approach in the treatment of NBCCS patients. **Keywords:** Gorlin-Goltz syndrome, nevoid basal cell carcinoma syndrome, odontogenic keratocyst, orthodontic treatment, multidisciplinary approach.

TEKRARLAYAN ODONTOJENİK KERATOKİSTLER EŞLİĞİNDE GORLİN-GOLTZ SENDROMLU BİR HASTADA MULTİDİSİPLİNER ORTODONTİK TEDAVİSİ

MULTIDISCIPLINARY ORTHODONTIC TREATMENT OF A PATIENT WITH GORLIN-GOLTZ SYNDROME ACCOMPANIED BY RECURRENT ODONTOGENIC KERATOCYSTS

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ÖZET

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ABSTRACT

Gorlin-Goltz syndrome, also known as nevoid basal cell carcinoma syndrome (NBCCS), is a rare craniofacial disorder characterized by multiple odontogenic keratocysts, cutaneous lesions, and skeletal anomalies. In this case report, the multidisciplinary orthodontic treatment of a 16-year-old male NBCCS

patient who had undergone treatment for numerous odontogenic cysts prior to orthodontic therapy, and who presented with a skeletal Class III relationship, extensive maxillary anterior bone loss, and impacted canine teeth in both the mandible and maxilla, is presented. A multi-stage approach was followed in the treatment plan. At the outset of treatment, the impacted mandibular right canine was extracted, as its eruption path was unfavorable and it could not be brought into the oral cavity. The maxillary left canine, on the other hand, was incorporated into the arch through orthodontic extrusion. Subsequently, the space remaining distal to the right maxillary canine was closed. The mandibular right lateral incisor was reshaped in such a way as to functionally take over the role of the missing canine. Finally, distalization was performed in the right maxillary posterior region in order to establish the sagittal relationship. Two new cystic lesions that developed during the course of treatment were enucleated; this situation resulted in significant buccal bone loss around the left maxillary canine tooth and led to the extraction of the right maxillary lateral incisor. Despite the cyst recurrences that occurred during treatment, an acceptable dental arch alignment, a functional occlusion, and an occlusion suitable for future prosthetic rehabilitation were able to be achieved. This case demonstrates the importance of accurate orthodontic planning and a multidisciplinary approach in the treatment of NBCCS patients. **Keywords:** Gorlin-Goltz syndrome, nevoid basal cell carcinoma syndrome, odontogenic keratocyst, orthodontic treatment, multidisciplinary approach.

DUDAK DAMAK YARIKLI BİREYLERDE MANDİBULAR TRABEKÜLER KEMİK YAPISI İLE KONDİL VE RAMUS MORFOMETRİSİNİN DEĞERLENDİRİLMESİ

EVALUATION OF MANDIBULAR TRABECULAR BONE STRUCTURE AND CONDYLE AND RAMUS MORPHOMETRY IN INDIVIDUALS WITH CLEFT LIP AND PALATE

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ÖZET

Dudak damak yarıkları (DDY), kraniyofasiyal gelişimi etkileyen konjenital anomalilerin başında gelir. Bu çalışmada, dudak damak yarıklı bireylerde mandibular trabeküler kemik yapısı ile kondil ve ramus morfometrisi değerlendirilmiştir. Çalışmamızda, çift taraflı DDY (Grup 1), sol tek taraflı DDY (Grup 2), yarıksız iskeletsel Sınıf III (Grup 3) ve yarıksız iskeletsel Sınıf I (Grup 4) olmak üzere dört grup oluşturulmuş ve her gruba 25 birey dahil edilmiştir. Panoramik radyograflarda mandibulaya 50 × 50 piksellik ilgi alanları yerleştirilerek fraktal analiz ve histogram analizi uygulanmış; mandibular morfolojik parametreler ise AutoCAD yazılımıyla ölçülmüştür. Verilerin analizinde tek yönlü varyans analizi (ANOVA) ve post-hoc Tukey testi kullanılmış; anlamlılık düzeyi $p<0,05$ kabul edilmiştir. Fraktal boyutta, sağ tarafta kondiler ($p=0,005$; Grup1-Grup4 $p=0,003$) ve angular ($p=0,001$; Grup2-Grup4 $p=0,001$) bölgelerde; sol tarafta ise kondiler ($p=0,015$; Grup2-Grup4 $p=0,010$), koronoid ($p=0,007$; Grup2-Grup4 $p=0,005$) ve angular ($p=0,001$; Grup1-Grup4 $p=0,028$, Grup2-Grup4 $p=0,001$, Grup3-Grup4 $p=0,003$) bölgelerde anlamlı farklılıklar saptanmıştır. Histogram analizinde, sağ tarafta angulus ($p=0,027$; Grup1-Grup4 $p=0,022$) ve korpus ($p=0,002$; Grup1-Grup3 $p=0,026$, Grup1-Grup4 $p=0,030$, Grup2-Grup3 $p=0,027$, Grup2-Grup4 $p=0,032$) bölgesinde; sol tarafta ise yalnızca korpus bölgesinde ($p<0,001$; Grup2-Grup4 $p<0,001$, Grup1-Grup4 $p=0,003$) anlamlı gri seviye farkları belirlenmiştir. Morfometrik parametreler arasında yalnızca Kondiler Yükseklik-1 (KY1) hem sağ ($p<0,001$; Grup1-Grup3 $p=0,022$, Grup1-Grup4 $p<0,001$) hem sol ($p<0,001$) tarafta anlamlı farklılık göstermiş; en düşük değerler DDY gruplarında, en yüksek değerler Sınıf I kontrol grubunda saptanmıştır. Bulgular bir bütün olarak değerlendirildiğinde, hem DDY'nin hem de iskeletsel Sınıf III maloklüzyonun mandibular trabeküler yapıyı ve kondil ve ramus simetrisinde farklılıklara yol açabileceğini ortaya koymuştur.

Anahtar Kelimeler: Dudak damak yarığı, mandibula, fraktal analiz, histogram analizi, kondil–ramus morfometrisi.

ABSTRACT

Cleft lip and palate (CLP) is among the leading congenital anomalies affecting craniofacial development. In this study, mandibular trabecular bone structure and condyle and ramus morphometry were evaluated in individuals with CLP. Four groups were formed: bilateral CLP (Group 1), left unilateral CLP (Group 2), non-cleft skeletal Class III (Group 3), and non-cleft skeletal Class I (Group 4), with 25 subjects included in each group. On panoramic radiographs, 50 × 50-pixel regions of interest were placed on the mandible to perform fractal analysis and histogram analysis, while mandibular morphological parameters were measured using AutoCAD software. Data were analyzed using one-way analysis of variance (ANOVA) and post-hoc Tukey tests; the significance level was accepted as $p<0.05$. In terms of fractal dimension, significant differences were found on the right side in the condylar

(p=0.005; Group1-Group4 p=0.003) and angular (p=0.001; Group2-Group4 p=0.001) regions, and on the left side in the condylar (p=0.015; Group2-Group4 p=0.010), coronoid (p=0.007; Group2-Group4 p=0.005), and angular (p=0.001; Group1-Group4 p=0.028, Group2-Group4 p=0.001, Group3-Group4 p=0.003) regions. On histogram analysis, significant gray-level differences were determined on the right side in the angulus (p=0.027; Group1-Group4 p=0.022) and corpus (p=0.002; Group1-Group3 p=0.026, Group1-Group4 p=0.030, Group2-Group3 p=0.027, Group2-Group4 p=0.032) regions, and on the left side exclusively in the corpus region (p<0.001; Group2-Group4 p<0.001, Group1-Group4 p=0.003). Among the morphometric parameters, only Condylar Height-1 (CH1) showed a significant difference on both the right (p<0.001; Group1-Group3 p=0.022, Group1-Group4 p<0.001) and left (p<0.001) sides, with the lowest values found in the CLP groups and the highest in the Class I control group. Taken together, these findings demonstrate that both CLP and skeletal Class III malocclusion may lead to differences in mandibular trabecular structure and in condyle and ramus symmetry.

Keywords: Cleft lip and palate, mandible, fractal analysis, histogram analysis, condyle–ramus morphometry.

1989–2026 YILLARI ARASINDAKİ HİZMET PAZARLAMASI VE MÜŞTERİ MEMNUNİYETİNE DAİR AKADEMİK YAYINLARIN BİBLİYOMETRİK İNCELEMESİ

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ÖZET

ÖZET

Bu çalışma, 1989–2026 yılları arasında hizmet pazarlaması ve müşteri memnuniyeti konularında gerçekleştirilen akademik yayınların yapısını, gelişim dinamiklerini ve eğilimlerini bibliyometrik analiz yöntemiyle incelemeyi amaçlamaktadır. Araştırma kapsamında elde edilen veriler; yıllık bilimsel üretim trendleri, en çok yayın yapan dergiler, öne çıkan ve en çok atıf alan yazarlar ile yayınların coğrafi dağılımı (ülkeler) doğrultusunda değerlendirilmiştir. Bulgular, 1989–1996 yılları arasında kısıtlı bir yayın hacmiyle emekleme aşamasında olan literatürün, 1997 sonrası ivme kazanarak 2000'li yıllarda olgunlaşma dönemine girdiğini ve 2024 yılında 25 makale ile tarihsel zirvesine ulaştığını göstermektedir.

Yayın mecraları açısından *Journal of Services Marketing* alandaki 37 çalışma ile teorik ve ampirik omurgayı oluşturan en baskın kaynak olarak öne çıkmaktadır. Yazar bazlı analizlerde Timothy L. Keiningham en üretken isimler arasında yer alırken; Ko de Ruyter, Dawn Iacobucci ve Amy L. Ostrom yüksek atıf sayılarıyla alanın metodolojik ve kavramsal otoriteleri olarak tespit edilmiştir. Ülke bazlı yayın dağılımında ise ABD 38 makale ile liderliğini korurken, Çin ve Hindistan gibi yükselen Asya ekonomilerinin gösterdiği güçlü performans, hizmet pazarlaması ve müşteri memnuniyeti araştırmalarının küresel düzeydeki stratejik önemini açıkça ortaya koymaktadır.

Anahtar Kelimeler: Hizmet Pazarlaması, Müşteri Memnuniyeti, Bibliyometrik Analiz

ABSTRACT

This study aims to examine the structure, developmental dynamics, and trends of academic publications on service marketing and customer satisfaction published between 1989 and 2026 through bibliometric analysis. The data obtained within the scope of the research were evaluated in terms of annual scientific production trends, top publishing journals, prominent and most cited authors, and the geographical distribution of publications by country. The findings indicate that the literature, which was in its infancy with a limited volume of publications between 1989 and 1996, gained momentum after 1997, reached a period of maturity in the 2000s, and attained its historical peak in 2024 with 25 articles.

In terms of publication venues, the *Journal of Services Marketing* stands out as the most dominant source forming the theoretical and empirical backbone of the field, with 37 publications. In the author-based analysis, Timothy L. Keiningham ranks among the most prolific authors, while Ko de Ruyter, Dawn Iacobucci, and Amy L. Ostrom are identified as the methodological and conceptual authorities of the domain due to their high citation counts. Regarding geographical distribution, the USA maintains its leadership with 38 articles, while the strong performance of emerging Asian economies such as China

and India clearly demonstrates the global strategic importance of service marketing and customer satisfaction research.

Keywords: Service Marketing, Customer Satisfaction, Bibliometric Analysis

GİRİŞ

Gelişen teknoloji, küreselleşme ve tüketici beklentilerindeki hızlı değişimler, günümüz ekonomilerinde hizmet sektörünün stratejik önemini her geçen gün artırmaktadır. Mal odaklı geleneksel pazarlama anlayışından hizmet odaklı mantığa (*Service-Dominant Logic*) geçişle birlikte (Vargo ve Lusch, 2004), hizmet pazarlaması işletmelerin sürdürülebilir rekabet üstünlüğü elde etmelerinde kritik bir unsur haline gelmiştir (Zeithaml vd., 1985). Bu süreçte, sunulan hizmetin kalitesi ile doğrudan ilintili olan müşteri memnuniyeti kavramı; müşteri sadakati, pozitif kulaktan kulağa iletişim (WOM) ve işletmelerin uzun vadeli finansal performansının temel belirleyicisi olarak literatürdeki merkezî konumunu korumaktadır (Oliver, 1980; Parasuraman vd., 1988; Fornell, 1992; Keiningham vd., 2007).

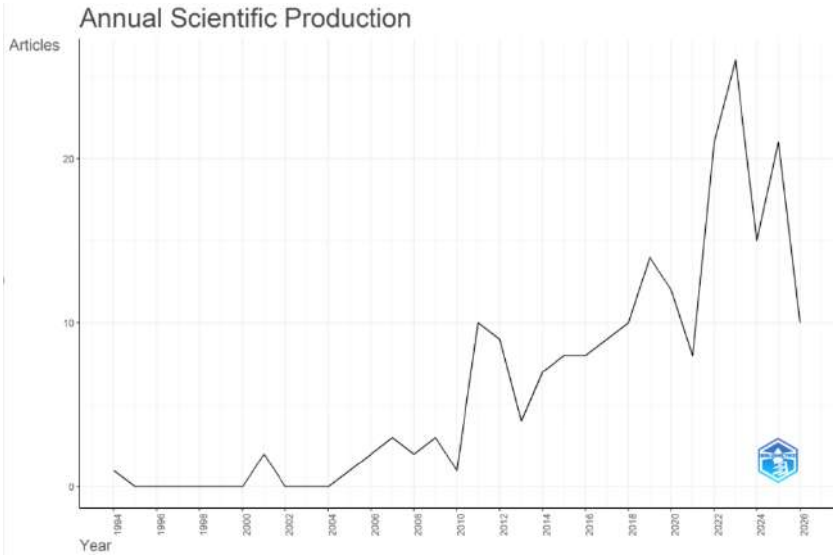
Pazarlama yazınında son kırk yılda yaşanan bu dinamik dönüşüm, hizmet pazarlaması ve müşteri memnuniyeti alanındaki akademik üretimin de hızla çeşitlenmesine ve genişlemesine yol açmıştır (Grönroos, 1994; Bitner vd., 2000; Ostrom vd., 2010). Özellikle dijitalleşme, yapay zeka entegrasyonu ve değişen tüketici davranışları, konunun farklı disiplinlerle kesişerek yeni araştırma alanları üretmesini sağlamıştır (Huang ve Rust, 2018; Larivière vd., 2017). Bu doğrultuda, söz konusu alanda biriken geniş külliyatın mevcut durumunu, tarihsel gelişimini ve entelektüel yapısını bütüncül bir bakış açısıyla ortaya koymak büyük bir akademik gereklilik olarak öne çıkmaktadır (Donthu vd., 2021).

Bu çalışmanın amacı, 1989–2026 yılları arasında hizmet pazarlaması ve müşteri memnuniyeti odağında gerçekleştirilen akademik yayınları bibliyometrik analiz yöntemiyle incelemektir. Araştırma kapsamında; yıllık bilimsel üretim trendleri, öne çıkan dergiler, alanda metodolojik ve kavramsal otoriteler olarak kabul edilen araştırmacılar ve yayınların küresel ölçekteki coğrafi dağılımları haritalandırılmıştır. Elde edilen bulgular, literatürün tarihsel seyrini ve evrilen odağını görünür kılarken, gelecekteki ampirik ve teorik araştırmalara ışık tutacak panoramik bir çerçeve sunmaktadır.

ARAŞTIRMA VE BULGULAR

Bibliyometrik yaklaşımların disiplinler arası çalışmalarda kullanımı, geniş literatür yığınlarının sistematik olarak çözümlenmesine ve karmaşık araştırma sahalarının yapısal haritasının çıkarılmasına olanak tanıyarak bilimsel süreçte giderek daha fazla öne çıkmaktadır. Bilim haritalama çalışmaları, doğası gereği yüksek teknik gereksinimlere sahip, çok katmanlı ve özel yazılım desteği gerektiren süreçleri kapsamaktadır. Bu noktada, akademik literatürde sıkça tercih edilen "bibliometrix" R paketi, bibliyometrik analizlerin iş akışını standart bir yapıya oturtarak araştırmacılara entegre ve dinamik bir çözüm çerçevesi sağlamaktadır (Aria ve Cuccurulloi 2017). Bilim haritalama, temelde belirli bir disiplinin entelektüel, kavramsal ve sosyal ağlarını görselleştiren tekniklerle analiz edilmesine odaklanmaktadır. Bibliyometrik analizler, bilimsel çıktının nicel olarak ölçülmesinde veri madenciliği, temizleme, analiz ve yorumlama gibi katı bir hiyerarşiyi takip etmektedir. Özellikle veri ön işleme aşaması, yazar isimlerindeki tutarsızlıkların, atıf kayıtlarındaki tekrarların ve yazım kusurlarının giderilmesi bakımından, ortaya çıkan sonuçların geçerliliği ve güvenilirliği için hayati bir önem taşımaktadır (Cobo vd. , 2011). Bu çalışma kapsamında, belirlenen araştırma sahasına dair literatürün nicel boyutu bibliyometrik yöntemlerle incelenmiştir. Bu analizlerle, çalışma alanının kavramsal çerçevesi, entelektüel gelişim süreci ve yazar iş birliği ağları sistematik bir şekilde haritalandırılmıştır.

Tablo 1. Yayınların Yıllara Göre Dağılımı



1989–2026 yılları arasında hizmet pazarlaması ve müşteri memnuniyeti literatüründe gerçekleştirilen bilimsel üretim, zaman içinde belirgin dönüşüm ve kırılma noktaları sergilemektedir. 1989–1996 kapsayısındaki ilk dönemde yıllık yayın sayısının kısıtlı kalması, kavramsal çerçevenin henüz emekleme aşamasında olduğuna işaret ederken; 1997 yılı itibarıyla başlayan ivme, 2000 yılında 19 makale ile ilk tepe noktasına ulaşmıştır. 2001–2022 yılları arasında dalgalı ancak niteliksel olarak olgunlaşan bir grafik çizen literatür; 2008, 2015 ve takip eden yıllarda düzenli yüksek üretim seviyelerini koruyarak disiplinler arası bir nitelik kazanmıştır.

Araştırma trendinin en radikal artışı ise 2023 sonrası gözlenmiş ve yayın sayısı 2024 yılında 25 makale ile tarihsel zirvesine ulaşmıştır. Bu belirgin yükseliş, dijitalleşme, yapay zeka uygulamaları ve yeni hizmet modellerinin pazarlama disiplinine entegrasyonunun akademide yarattığı güçlü dinamizm ile açıklanabilir. 2025–2026 döneminde gözlenen düşüş eğilimi ise alanın doygunluğa ulaşmasından ziyade, veri tabanlarındaki indeksleme ve veri çekme süreçlerinin henüz tamamlanmamış olmasından kaynaklanan dönemsel bir teknik gecikmeyi yansıtmaktadır.

Tablo 2. En Çok Çalışma Yapılan Dergiler

Kaynak	**Çalışma Sayısı**
JOURNAL OF SERVICES MARKETING	37
DEVELOPMENTS IN MARKETING SCIENCE: PROCEEDINGS OF THE ACADEMY OF MARKETING SCIENCE	17
EUROPEAN JOURNAL OF MARKETING	16
SERVICES MARKETING QUARTERLY	10
EMERALD EMERGING MARKETS CASE STUDIES	9
INTERNATIONAL JOURNAL OF SERVICE INDUSTRY MANAGEMENT	9
INTERNATIONAL JOURNAL OF BANK MARKETING	8
JOURNAL OF SERVICE MANAGEMENT	8
INTEGRATING AI-DRIVEN TECHNOLOGIES INTO SERVICE MARKETING	7
COGENT BUSINESS AND MANAGEMENT	6

1989–2026 yılları arasında hizmet pazarlaması ve müşteri memnuniyeti konusunu en sık ele alan yayın kaynakları incelendiğinde, literatürün hem alana özgü uzmanlaşmış dergiler hem de genel pazarlama mecraları etrafında kümelendiği görülmektedir. Yayın sayısına göre ilk sırada yer alan *Journal of Services Marketing* (37 çalışma), konunun teorik ve ampirik gelişiminde anahtar bir role sahiptir. Bunun

yanı sıra *Developments in Marketing Science* (17) ve *European Journal of Marketing* (16) gibi prestijli platformlar, alanın genel pazarlama yazınındaki stratejik ağırlığını koruduğunu kanıtlamaktadır.

Yayın dağılımı sektörel ve teknolojik odak açısından değerlendirildiğinde; *International Journal of Bank Marketing* (8) bankacılık sektörünün hizmet kalitesi ve memnuniyet odaklı araştırmalardaki baskınlığını gösterirken, *Emerald Emerging Markets Case Studies* (9) konunun gelişmekte olan pazarlardaki uygulama boyutuna dikkat çekmektedir. Son sırada yer alan *Integrating AI-Driven Technologies into Service Marketing* (7) başlıklı kaynak ise, hizmet pazarlaması literatürünün geleneksel kalıplardan sıyrılarak yapay zeka ve dijitalleşme eksenli yeni bir araştırma boyutuna evrildiğini açıkça ortaya koymaktadır.

Tablo 3. En Çok Yayın Yapan Yazarlar

Yazarlar	Makale Sayısı
KEININGHAM, TIMOTHY L.	6
AKSOY, LERZAN	5
DE RUYTER, KO	5
SHARMA, PIYUSH	5
DHAWAN, ABHINAV	4
MATHUR, RAJIV	4
IACOBUCCI, DAWN	3
LEMMINK, JOS	3
OSTROM, AMY L.	3
OYEWOLE, PHILEMON	3

1989–2026 yılları arasında hizmet pazarlaması ve müşteri memnuniyeti literatürüne en yüksek katkıyı sağlayan araştırmacılar incelendiğinde, alanın müşteri sadakati, hizmet kalitesi ve müşteri deneyimi konularında dünyaca tanınan yetkin akademisyenler etrafında şekillendiği görülmektedir. Yayın sayısı bakımından Timothy L. Keiningham (6 makale) ilk sırada yer alırken; Lerzan Aksoy, Ko de Ruyter ve Piyush Sharma (5'er makale) alana en fazla katkı sunan diğer öncü isimler olmuştur. Ayrıca Abhinav Dhawan ve Rajiv Mathur (4'er makale) ile Dawn Iacobucci, Jos Lemmink, Amy L. Ostrom ve Philemon Oyewole (3'er makale) literatürün ampirik ve teorik omurgasını destekleyen stratejik araştırmacılar arasında öne çıkmaktadır.

Listede yer alan isimler (özellikle Keiningham, Aksoy ve de Ruyter gibi isimler), hizmet pazarlaması yazınında müşteri memnuniyetinin finansal getirilere dönüşmesi, Net Tavsiye Skoru (NPS) ve hizmette dijital dönüşüm konularına yön veren çekirdek araştırmacılardan oluşmaktadır. Bu durum, incelenen veri setinin yüksek akademik niteliğe sahip olduğunu ve alanın tesadüfi yayınlarla değil, disiplinin kurucu ve yön verici lider akademisyenlerinin çalışmalarıyla beslendiğini kanıtlamaktadır.

Tablo 4. En Çok Atıf Alan Yazarlar

Yazarlar	Toplam Atıf
DE RUYTER, KO	354
IACOBUCCI, DAWN	273
OSTROM, AMY L.	273
KEININGHAM, TIMOTHY L.	154
AKSOY, LERZAN	84
LEMMINK, JOS	52
OYEWOLE, PHILEMON	33
DHAWAN, ABHINAV	28

MATHUR, RAJIV	28
SHARMA, PIYUSH	28

1989–2026 yılları arasında hizmet pazarlaması ve müşteri memnuniyeti literatüründe en çok atıf alan yazarlar incelendiğinde, akademik etki gücü yüksek çekirdek bir araştırmacı grubunun varlığı öne çıkmaktadır. Ko de Ruyter 354 atıf ile alanın bilimsel etki değeri en yüksek araştırmacısı konumundayken, kendisini 273'er atıf ile Dawn Iacobucci ve Amy L. Ostrom takip etmektedir. Ayrıca Timothy L. Keiningham (154 atıf) ve Lerzan Aksoy (84 atıf) alanda yön verici teorik ve ampirik çalışmalara imza atan diğer öncü isimler olarak dikkat çekmektedir.

Tablo 3 (En Çok Yayın Yapan Yazarlar) ile Tablo 4 (En Çok Atıf Alan Yazarlar) birlikte değerlendirildiğinde; Keiningham, Aksoy, de Ruyter, Iacobucci ve Ostrom gibi akademisyenlerin hem yayın hacmi hem de atıf etkisi açısından üst sıralarda yer aldığı görülmektedir. Bu durum, adı geçen yazarların yalnızca niceliksel (yayın sayısı) olarak değil, aynı zamanda niteliksel olarak da hizmet kalitesi, müşteri sadakati ve hizmet sistemleri yazınının yönünü çizen "metodolojik ve kavramsal otorite" konumunda olduklarını kanıtlamaktadır.

Tablo 5. Alanda En Çok Yayın Yapan Ülkeler

Kurum	Makale Sayısı
ABD	38
ÇİN	19
HİNDİSTAN	17
AVUSTRALYA	14
BİRLEŞİK KRALLIK	8
ENDONEZYA	5
GÜNEY KORE	5
MALEZYA	5
HOLLANDA	5
TÜRKİYE	4

1989–2026 yılları arasında hizmet pazarlaması ve müşteri memnuniyeti alanında üretilen akademik yayınların coğrafi dağılımı incelendiğinde, Batı merkezli geleneksel akademik liderliğin yanı sıra Asya pazarlarının da güçlü bir bilimsel ivme yakaladığı görülmektedir. ABD, toplam 38 makale ile literatürün açık ara lideri konumunda olup alanın teorik ve kavramsal temellerinin şekillenmesinde baskın bir role sahiptir. ABD'yi sırasıyla Çin (19 makale), Hindistan (17 makale) ve Avustralya (14 makale) takip etmektedir. Birleşik Krallık ise 8 yayın ile Avrupa genelindeki bilimsel katkıya öncülük eden ana merkezlerden biri olmuştur.

Tablodaki ülke dağılımı bütüncül olarak değerlendirildiğinde; Endonezya, Güney Kore, Malezya ve Hollanda'nın 5'er yayın ile orta segmentte dengeli bir akademik üretim sergilediği, Türkiye'nin ise 4 makale ile ilk 10 ülke arasında yer bularak uluslararası literatüre entegre olduğu anlaşılmaktadır. Özellikle Çin, Hindistan, Malezya ve Endonezya gibi yükselen Asya ekonomilerinin ön sıralarda yer alması, hizmet sektörünün bu bölgelerdeki hızlı büyümesine ve müşteri odaklı stratejilerin bu pazarlardaki ampirik araştırmalarda kazandığı stratejik öneme işaret etmektedir.

SONUÇ

Bu çalışmada, 1989–2026 yılları arasında hizmet pazarlaması ve müşteri memnuniyeti yazınında gerçekleştirilen akademik yayınlar bibliyometrik analiz yöntemiyle incelenmiş; alanın tarihsel evrimi, entelektüel yapısı, öne çıkan mecraları, yön verici araştırmacıları ve coğrafi kümelenmeleri bütüncül bir yaklaşımla ortaya koyulmuştur. Elde edilen bulgular, disiplinin son kırk yılda geçirdiği kavramsal ve yöntemsel dönüşümü doğrular niteliktedir.

Literatürün gelişim seyrine bakıldığında, 1989–1996 yılları kapsayısındaki ilk dönemde yayın sayısının son derece kısıtlı kaldığı ve konunun emekleme aşamasında olduğu görülmektedir. 1990'ların sonundan itibaren hizmet sektörünün küresel ekonomideki stratejik ağırlığının artması ve hizmet odaklı mantığın (*Service-Dominant Logic*) ivme kazanmasıyla birlikte (Vargo ve Lusch, 2004), yayın sayılarında belirgin bir sıçrama yaşanmıştır. 2000–2022 yılları arasında dalgalı ancak sürdürülebilir bir büyüme sergileyen literatür, 2023 sonrası döneme gelindiğinde ise tarihsel bir patlama yaşamış ve 2024 yılında 25 makale ile zirve noktasına ulaşmıştır. Bu durum; yapay zeka, otomasyon ve dijital hizmet modellerinin pazarlama disiplinine entegrasyonunun akademide yarattığı güçlü araştırma dinamizmi ile açıklanabilir (Huang ve Rust, 2018; Larivière vd., 2017).

Yayın yapılan dergiler ve araştırmacı profilleri incelendiğinde, literatürün hem alana özgü uzmanlaşmış kaynaklar hem de prestijli genel pazarlama platformları etrafında kümelendiği anlaşılmaktadır. *Journal of Services Marketing* (37 çalışma) ve *European Journal of Marketing* (16 çalışma) gibi dergiler alanın omurgasını oluştururken; *International Journal of Bank Marketing* ve *Integrating AI-Driven Technologies into Service Marketing* gibi yayınlar, müşteri memnuniyeti araştırmalarının sektörel ve teknolojik odaklı yeni boyutlar kazandığını kanıtlamaktadır (Ostrom vd., 2015; Rust, 2020).

Yazar ve atıf analizleri ise alanın kurucu ve yön verici otoritelerini net biçimde ortaya koymuştur. Timothy L. Keiningham, Lerzan Aksoy, Ko de Ruyter, Dawn Iacobucci ve Amy L. Ostrom gibi araştırmacılar hem yayın hacmi hem de yüksek atıf sayılarıyla (de Ruyter: 354 atıf, Iacobucci ve Ostrom: 273'er atıf) literatürün kavramsal çerçevesini çizen temel aktörler olmuşlardır. Söz konusu isimlerin müşteri memnuniyetinin finansal getirilere dönüşmesi, hizmet kalitesi ölçümü ve müşteri deneyimi alanlarındaki ampirik katkıları, literatürün yöntemsel olgunluğuna doğrudan yön vermiştir (Oliver, 1980; Parasuraman vd., 1988; Keiningham vd., 2007).

Yayınların coğrafi dağılımı değerlendirildiğinde, ABD'nin (38 makale) geleneksel akademik liderliğini koruduğu; ancak Çin (19 makale) ve Hindistan (17 makale) başta olmak üzere yükselen Asya ekonomilerinin hizmet pazarlaması ve müşteri memnuniyeti araştırmalarında son derece baskın bir konuma yükseldiği tespit edilmiştir. Bu durum, küresel hizmet ekonomisinin ağırlık merkezinin doğuya kayması ve gelişmekte olan pazarlardaki tüketici davranışlarının akademide gördüğü yoğun ilgi ile paralellik göstermektedir (Donthu vd., 2021).

Gelecek araştırmalar için, özellikle dijitalleşen hizmet ortamlarında üretken yapay zeka uygulamalarının, insansız hizmet etkileşimlerinin ve kişiselleştirilmiş müşteri deneyimlerinin müşteri memnuniyeti ile sadakati üzerindeki uzun vadeli etkilerinin ampirik olarak incelenmesi önerilmektedir (Huang ve Rust, 2021). Bu çalışma, hizmet pazarlaması ve müşteri memnuniyeti alanındaki geniş külliyatı sistemli bir şekilde haritalandırarak araştırmacılara ve uygulayıcılara rehberlik edecek panoramik bir altyapı sunmaktadır.

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GİRİŞİMCİLİK VE YEŞİL İNOVASYON LİTERATÜRÜNÜN BİBLİYOMETRİK ANALİZİ

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ÖZET

Bu çalışma, girişimcilik ve yeşil inovasyon kesişiminde yer alan akademik literatürü bibliyometrik analiz yöntemiyle inceleyerek alanın entelektüel yapısını, gelişim dinamiklerini ve küresel eğilimlerini ortaya koymayı amaçlamaktadır. Araştırma kapsamında, söz konusu literatürün yıllara göre bilimsel üretim seyri, en çok yayın yapılan dergiler, öne çıkan yazar ve atıf ağları ile ülkelerin coğrafi dağılımı detaylı bir şekilde analiz edilmiştir. Elde edilen bulgular, 2011-2018 yılları arasında sınırlı bir yayın hacmiyle emekleme döneminde olan literatürün, özellikle 2021 yılı sonrasında üssel bir büyüme trendine girerek 2025 yılında zirve noktasına ulaştığını göstermektedir.

Görsel ve sayısal verilerin analizi, alanın disiplinlerarası bir yayın yelpazesine sahip olduğunu ve *Sustainability*, *Business Strategy and the Environment* ile *Journal of Cleaner Production* gibi dergilerin ana merkezleri oluşturduğunu kanıtlamaktadır. Yazarların atıf ve yayın kapasiteleri incelendiğinde, Makhloufi, Lahcene gibi isimlerin öncülüğünde güçlü ortak yazarlı araştırma ağlarının varlığı dikkat çekmektedir. Coğrafi açıdan bakıldığında ise Çin liderliğinde Hindistan, Endonezya ve Malezya gibi Yükselen Asya ekonomilerinin akademik üretimde ezici bir baskınlığa sahip olduğu görülmektedir. Sonuç olarak çalışma, yeşil inovasyon ve girişimcilik alanındaki akademik ilginin özellikle hızlı sanayileşen ve ekolojik dönüşüm ihtiyacı duyan gelişmekte olan ülkelerde olgunlaşarak küresel bir öncelik haline geldiğini ortaya koymaktadır.

Anahtar Kelimeler: Girişimcilik, Yeşil İnovasyon, Bibliyometrik Analiz

ABSTRACT

This study aims to reveal the intellectual structure, development dynamics, and global trends of the academic literature at the intersection of entrepreneurship and green innovation using bibliometric analysis. Within the scope of the research, the scientific production trajectory over the years, top publishing journals, prominent authors and citation networks, and the geographic distribution of countries were systematically analyzed. The findings indicate that the literature—which remained in an embryonic stage with limited publication volume between 2011 and 2018—entered an exponential growth trend particularly after 2021, reaching its peak in 2025.

The analysis reveals an interdisciplinary publishing landscape, with journals such as *Sustainability*, *Business Strategy and the Environment*, and *Journal of Cleaner Production* serving as primary publishing hubs. An examination of author citations and publication output highlights strong co-authorship networks led by prominent researchers such as Lahcene Makhloufi. Geographically, emerging Asian economies—led by China, followed by India, Indonesia, and Malaysia—dominate the scientific output. In conclusion, the study demonstrates that academic interest in green innovation and

entrepreneurship has matured into a global strategic priority, driven largely by rapidly industrializing nations facing ecological transformation needs.

Keywords: Entrepreneurship, Green Innovation, Bibliometric Analysis

GİRİŞ

Son yıllarda küresel ölçekte derinleşen iklim krizi, doğal kaynakların hızla tükenmesi ve çevre kirliliğindeki artış, iktisadi ve yönetsel düzenin yeniden yapılandırılmasını zorunlu kılmıştır. Geleneksel üretim ve tüketim modellerinin ekolojik dengeler üzerinde yarattığı tahribat, sürdürülebilirlik kavramını iş dünyasının ve akademi alanının temel odak noktalarından biri haline getirmiştir (Elkington, 1997; Schaltegger ve Synnestvedt, 2002). Bu dönüşüm sürecinde, çevresel sorunların çözümünde sadece kısıtlayıcı politikalar veya yasal düzenlemeler değil, aynı zamanda yenilikçi ve piyasa odaklı yaklaşımlar da kritik bir rol oynamaktadır. Bu noktada, girişimcilik dinamikleri ile çevresel duyarlılıkları bir araya getiren yeşil inovasyon (green innovation) kavramı, sürdürülebilir kalkınmanın en stratejik itici güçlerinden biri olarak ön plana çıkmaktadır (Chen vd., 2006; Schiederig vd., 2012).

Yeşil inovasyon, ürün, süreç, organizasyonel yapı veya pazarlama yöntemlerinde çevresel olumsuz etkileri en aza indirmeyi, enerji ve kaynak verimliliğini artırmayı ve doğaya duyarlı çözümler sunmayı hedefleyen yenilikçi uygulamalar bütünüdür (Fussler ve James, 1996; Driessen ve Hillebrand, 2002). Sürdürülebilir büyümenin yakalanmasında girişimciler; fırsatları tespit eden, yeşil teknolojileri ticarileştiren ve radikal inovasyonlarla pazarı dönüştüren ana aktörler konumundadır (Hall vd., 2010; Dean ve McMullen, 2007). Girişimcilik ekosisteminin yeşil inovasyon süreçleriyle entegre olması, sadece işletmelerin rekabet avantajı elde etmesini sağlamakla kalmamakta (Porter ve van der Linde, 1995), aynı zamanda toplumsal ve çevresel refahın eş zamanlı olarak artırılmasına da zemin hazırlamaktadır.

Söz konusu stratejik öneme paralel olarak, girişimcilik ve yeşil inovasyon kesişiminde yürütülen akademik araştırmalar son yıllarda ivmelenerek çok boyutlu bir nitelik kazanmıştır. Literatürde işletmelerin yeşil inovasyon benimseme dinamikleri (Dangelico ve Pujari, 2010), çevresel liderlik (Chen, 2011), kurum içi çevresel yönetim yetenekleri ve regülasyon baskıları (Jaffe vd., 1995) gibi pek çok konu farklı açılardan ele alınmıştır. Ancak, bu alanda üretilen bilimsel bilginin hacimsel artışı ve disiplinlerarası yayılımı, literatürün genel seyrini, yapısal eğilimlerini ve kilit aktörlerini bütüncül bir perspektifle değerlendirme ihtiyacını doğurmuştur (Zupic ve Čater, 2015).

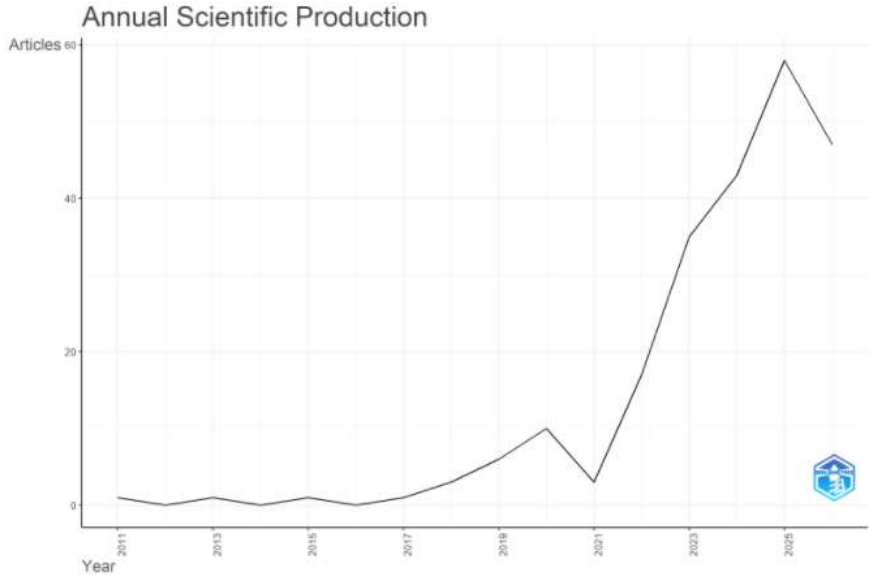
Bu ihtiyaca yanıt vermek amacıyla hazırlanan bu çalışmada, girişimcilik ve yeşil inovasyon literatürü bibliyometrik analiz yöntemiyle incelenmiştir. Bilimsel yayınların nicel ve nitel boyutlarını matematiksel ve istatistiksel tekniklerle haritalandırmaya olanak tanıyan bibliyometrik analiz (Donthu vd., 2021; Aria ve Cuccurullo, 2017), alanın tarihsel gelişimini ve entelektüel mimarisini somut verilerle ortaya koymaktadır. Çalışma kapsamındaki analizler; yayınların yıllara göre dağılımını, alandaki en etkili ve üretken dergileri, öne çıkan yazar ve atıf ağlarını ve coğrafi odak noktalarını kapsayacak şekilde kurgulanmıştır. Elde edilen bulgular, yeşil inovasyon ve girişimcilik alanındaki mevcut birikimi netleştirmeyi ve gelecekteki araştırmalar için stratejik yönelimler sunmayı amaçlamaktadır.

ARAŞTIRMA VE BULGULAR

Bibliyometrik yaklaşımların disiplinler arası çalışmalarda kullanımı, geniş literatür yığınlarının sistematik olarak çözümlenmesine ve karmaşık araştırma sahalarının yapısal haritasının çıkarılmasına olanak tanıyarak bilimsel süreçte giderek daha fazla öne çıkmaktadır. Bilim haritalama çalışmaları, doğası gereği yüksek teknik gereksinimlere sahip, çok katmanlı ve özel yazılım desteği gerektiren süreçleri kapsamaktadır. Bu noktada, akademik literatürde sıkça tercih edilen "bibliometrix" R paketi, bibliyometrik analizlerin iş akışını standart bir yapıya oturtarak araştırmacılara entegre ve dinamik bir çözüm çerçevesi sağlamaktadır (Aria ve Cuccurulloi 2017). Bilim haritalama, temelde belirli bir disiplinin entelektüel, kavramsal ve sosyal ağlarını görselleştiren tekniklerle analiz edilmesine odaklanmaktadır. Bibliyometrik analizler, bilimsel çıktının nicel olarak ölçülmesinde veri madenciliği, temizleme, analiz ve yorumlama gibi katı bir hiyerarşiyi takip etmektedir. Özellikle veri ön işleme aşaması, yazar isimlerindeki tutarsızlıkların, atıf kayıtlarındaki tekrarların ve yazım kusurlarının

giderilmesi bakımından, ortaya çıkan sonuçların geçerliliği ve güvenilirliği için hayati bir önem taşımaktadır (Cobo vd. , 2011). Bu çalışma kapsamında, belirlenen araştırma sahasına dair literatürün nicel boyutu bibliyometrik yöntemlerle incelenmiştir. Bu analizlerle, çalışma alanının kavramsal çerçevesi, entelektüel gelişim süreci ve yazar iş birliği ağları sistematik bir şekilde

Tablo 1. Yayınların Yıllara Göre Dağılımı



Girişimcilik ve yeşil inovasyon literatüründeki yıllık bilimsel yayın dağılımı (2011-2025/2026), konunun akademik alandaki gelişim seyrini ve artan önemini net bir şekilde ortaya koymaktadır. 2011-2018 yılları arasında oldukça sınırlı bir yayın hacmiyle (yılda 0-5 makale) seyreden literatür, emekleme dönemini simgelemektedir. 2018 sonrasında ivme kazanmaya başlayan çalışma sayısı, 2020 yılında ilk kayda değer zirvesini (yaklaşık 10 makale) görmüş, 2021 yılındaki kısa süreli düşüşün ardından ise belirgin bir üssel büyüme trendine girmiştir.

Özellikle 2021 yılı sonrasında gözlemlenen dik artış, yeşil inovasyon ve girişimcilik kesişiminin küresel akademik gündemde stratejik bir öncelik haline geldiğini göstermektedir. Bu ivmelenme ile birlikte yıllık yayın sayısı 2025 yılında yaklaşık 58 makale ile zirve noktasına ulaşmıştır. Grafik, sürdürülebilirlik ve çevre odaklı girişimcilik konularına yönelik akademik ilginin son yıllarda dramatik bir şekilde arttığını ve alanın olgunlaşma aşamasına geçerek geniş bir araştırmacı kitlesi tarafından benimsendiğini doğrulamaktadır.

Tablo 2. En Çok Çalışma Yapılan Dergiler

Kaynak	**Çalışma Sayısı**
SUSTAINABILITY (SWITZERLAND)	15
BUSINESS STRATEGY AND THE ENVIRONMENT	6
JOURNAL OF CLEANER PRODUCTION	6
INTERNATIONAL ENTREPRENEURSHIP AND MANAGEMENT JOURNAL	5
JOURNAL OF COMMERCIAL BIOTECHNOLOGY	5
JOURNAL OF OPEN INNOVATION: TECHNOLOGY, MARKET, AND COMPLEXITY	5
SPRINGER PROCEEDINGS IN BUSINESS AND ECONOMICS	5
TECHNOLOGY IN SOCIETY	5
ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH	4
SUSTAINABLE DEVELOPMENT	4

Girişimcilik ve yeşil inovasyon literatüründe en fazla yayın yapan dergilerin yer aldığı Tablo 2 incelendiğinde, konuların disiplinlerarası bir yayın platformu yelpazesinde ele alındığı görülmektedir. Toplam 15 çalışma ile *Sustainability (Switzerland)* dergisi, bu alandaki araştırmaların yayımlandığı açık ara en baskın kaynak olarak öne çıkmaktadır. Onu sırasıyla 6'şar çalışma ile *Business Strategy and the Environment* ve *Journal of Cleaner Production* takip etmektedir. Bu dağılım, yeşil inovasyon konusunun temelde sürdürülebilirlik, çevre yönetimi ve üretim süreçleri odaklı akademik yayın organlarında yoğun bir şekilde karşılık bulduğunu göstermektedir.

Bununla birlikte; *International Entrepreneurship and Management Journal*, *Journal of Open Innovation: Technology, Market, and Complexity* ve *Technology in Society* gibi 5'er çalışmaya sahip dergilerin listede bulunması, konunun sadece çevre bilimleriyle sınırlı kalmayıp işletme, girişimcilik ve teknoloji yönetimi disiplinleriyle de güçlü bir entegrasyon kurduğunu ortaya koymaktadır. Biyoteknoloji (*Journal of Commercial Biotechnology*) ve çevre kirliliği (*Environmental Science and Pollution Research*) gibi daha spesifik alan dergilerinin de listede yer alması, yeşil inovasyon ve girişimcilik yazınının teorik ve uygulama yönüyle çok boyutlu bir gelişim gösterdiğini kanıtlamaktadır

Tablo 3. En Çok Yayın Yapan Yazarlar

Yazarlar	Makale Sayısı
MAKHLOUFI, LAHCENE	6
MEIRUN, TANG	4
RAMAN, RAGHU	4
ALKA, T.A.	3
KYRIAKOPOULOS, GRIGORIOS L.	3
SURESH, M.	3
ARABATZIS, GARYFALLOS	2
BABER, HASNAN	2
CHALIKIAS, MILTIADIS	2
DZINGIRAI, MUFARO	2

Girişimcilik ve yeşil inovasyon alanında en çok bilimsel katkı sağlayan araştırmacıların yer aldığı Tablo 3 incelendiğinde, yazarların yayın üretim kapasiteleri arasındaki dağılım dikkat çekmektedir. Makale sayılarına göre oluşturulan sıralamada, toplam 6 çalışma ile Makhloufi, Lahcene ilk sırada yer alarak alanın önde gelen araştırmacılarından biri olarak öne çıkmaktadır. Kendisini 4'er makale ile Meirun, Tang ve Raman, Raghu takip etmekte; Alka, T.A., Kyriakopoulos, Grigorios L. ve Suresh, M. ise 3'er çalışma ile üst sıralarda yer bulmaktadır.

Yazarların makale sayılarındaki genel dağılım incelendiğinde, araştırmacı katkılarının oldukça parçalı bir yapı sunduğu ve tek bir baskın yazar grubunun varlığından ziyade geniş bir araştırmacı kitlesinin alana katkı sağladığı anlaşılmaktadır. En üretken yazarların dahi makale sayılarının birbirine yakın olması (2 ila 6 arasında), girişimcilik ve yeşil inovasyon yazınının tekil fikir önderlerinden ziyade çok sayıda bağımsız araştırmacı tarafından eş zamanlı geliştirilen dinamik bir yapıya sahip olduğunu göstermektedir.

Tablo 4. En Çok Atıf Alan Yazarlar

Yazarlar	Toplam Atıf
MAKHLOUFI, LAHCENE	313
MEIRUN, TANG	313
ARABATZIS, GARYFALLOS	169
CHALIKIAS, MILTIADIS	169

KYRIAKOPOULOS, GRIGORIOS L.	169
MAKHLOUFI, LAHCENE	168
ARABATZIS, GARYFALLOS	125
CHALIKIAS, MILTIADIS	125
KYRIAKOPOULOS, GRIGORIOS L.	125
RAMAN, RAGHU	90

Girişimcilik ve yeşil inovasyon literatüründe en yüksek akademik etkiye sahip araştırmacıların sunulduğu Tablo 4 incelendiğinde, yazarların aldıkları atıf sayılarına göre alan üzerindeki entelektüel nüfuzları belirginleşmektedir. Tablonun üst bölümünde yer alan toplam atıf verilerine göre Makhloufi, Lahcene ve Meirun, Tang 313'er atıf alarak zirveyi paylaşmaktadır. Bu iki ismi 169'ar atıf ile Arabatzis, Garyfallos, Chalikias, Miltiadis ve Kyriakopoulos, Grigorios L. takip etmektedir. Tablonun alt bölümündeki (muhtemelen yerel/doğrudan veya belirli bir veri tabanı bazlı) atıf dağılımında ise yine Makhloufi, Lahcene 168 atıf ile ilk sırada yer alırken; Arabatzis, Chalikias ve Kyriakopoulos 125'er atıf ile öne çıkmaktadır.

Elde edilen veriler, en çok yayın yapan yazarlar analiziyle (Tablo 3) paralellik göstermekte ve Makhloufi, Lahcene'in hem nitelik (yayın sayısı) hem de nicelik (atıf sayısı) açısından alandaki en baskın ve kilit isim olduğunu kanıtlamaktadır. Atıf sayılarındaki blok halinde eşitlikler (örneğin 313 ve 169 atıflı gruplar), söz konusu araştırmacıların bu alanda yüksek etki yaratan ortak yazarlı çalışmalarda bir araya geldiklerini göstermektedir. Bu durum, girişimcilik ve yeşil inovasyon yazınının güçlü yazar iş birlikleri ve ortak araştırma ağları etrafında şekillendiğini ve yön bulduğunu ortaya koymaktadır.

Tablo 5. Alanda En Çok Yayın Yapan Ülkeler

Ülke	Sıklık
Çin	115
Hindistan	50
Endonezya	44
Malezya	27
Pakistan	24
Yunanistan	16
İran	15
Suudi Arabistan	15
İspanya	14
ABD	14

Girişimcilik ve yeşil inovasyon literatüründe coğrafi üretkenliği gösteren Tablo 5 incelendiğinde, yayınların ülke bazlı dağılımında Gelişmekte Olan Asya ülkelerinin açık ara ezici bir üstünlüğe sahip olduğu görülmektedir. Çin, toplam 115 yayın sıklığı ile literatürün merkezinde yer alarak bu alandaki araştırmalara tartışmasız bir liderlik etmektedir. Çin'i sırasıyla Hindistan (50), Endonezya (44), Malezya (27) ve Pakistan (24) gibi yine Yükselen Asya pazarında yer alan ülkeler takip etmektedir.

Bu coğrafi yoğunlaşma, hızlı sanayileşme ve çevre kirliliği gibi büyük ölçekli ekolojik sorunlarla karşı karşıya kalan gelişmekte olan ekonomilerin, yeşil dönüşümü ve sürdürülebilir girişimciliği stratejik bir zorunluluk olarak gündemlerine aldıklarını doğrulamaktadır. Batı ekonomilerinden Yunanistan (16), İspanya (14) ve ABD (14) ile Orta Doğu'dan İran (15) ve Suudi Arabistan'ın (15) listede yer alması ise, yeşil inovasyon konusunun küresel çapta bir araştırma alanı haline geldiğini; ancak akademik üretim dinamiklerinin ağırlıklı olarak Doğu ve Güney Asya merkezli şekillendiğini ortaya koymaktadır.

SONUÇ

Bu çalışma, girişimcilik ve yeşil inovasyon alanındaki akademik literatürü 2011-2025/2026 dönemini kapsayacak şekilde bibliyometrik analiz yöntemiyle inceleyerek alanın entelektüel yapısını, gelişim dinamiklerini ve küresel odak noktalarını haritalandırmıştır. Elde edilen bulgular, konunun akademik alandaki seyrine ve gelecekteki araştırma yönelimlerine ilişkin önemli çıkarımlar sunmaktadır.

Analiz sonuçları, yeşil inovasyon ve girişimcilik yazınının belirgin aşamalardan geçerek olgunlaştığını göstermektedir. 2011-2018 yılları arasındaki düşük yayın hacmiyle karakterize edilen başlangıç döneminin ardından, özellikle 2021 yılı sonrasında üssel bir büyüme ivmesi yakalanmış ve 2025 yılında yayın sayısı zirve noktasına ulaşmıştır. Bu artış, küresel düzeyde derinleşen iklim krizi, net sıfır emisyon hedefleri ve sürdürülebilirlik odaklı regülasyonların akademik araştırma gündemini doğrudan şekillendirdiğini kanıtlamaktadır.

Yayın yapılan mecralar incelendiğinde, *Sustainability*, *Business Strategy and the Environment* ve *Journal of Cleaner Production* gibi çevre yönetimi ve sürdürülebilirlik odaklı dergilerin ağırlığı hissedilmekle birlikte; teknoloji yönetimi, işletme ve spesifik mühendislik alanlarındaki dergilerin varlığı konunun disiplinlerarası niteliğini vurgulamaktadır. Yazar ve atıf ağları analizi ise Lahcene Makhloufi gibi üretken isimlerin öncülüğünde güçlü iş birliği kümelerinin oluştuğunu ve alandaki bilgi birikiminin bu ortak araştırma ağları üzerinden yayıldığını göstermektedir.

Coğrafi dağılım açısından bakıldığında, literatürdeki en dikkat çekici bulgu Asya merkezli üretkenlik baskınlığıdır. Çin'in açık ara liderliğinde Hindistan, Endonezya, Malezya ve Pakistan gibi gelişmekte olan ekonomilerin yayın üretiminde üst sıralarda yer alması; hızlı sanayileşme, kentleşme ve ekolojik baskılarla yüzleşen yükselen pazarların yeşil dönüşümü stratejik bir gereklilik olarak benimsediklerini ortaya koymaktadır.

Gelecekteki araştırmalar için bu bulgular, yeşil girişimcilik ekosistemlerinin sadece gelişmiş Batı ekonomileri bağlamında değil, gelişmekte olan ülkelerin sosyo-ekonomik dinamikleri çerçevesinde derinlemesine incelenmesi gerektiğine işaret etmektedir. Ayrıca, yapay zekâ ve dijitalleşme gibi yıkıcı teknolojilerin yeşil inovasyon süreçlerine entegrasyonu (ikiz dönüşüm) ile odaklı nitel ve deneysel araştırmaların yürütülmesi, literatürün teorik ve pratik derinliğini artıracak potansiyel çalışma alanları olarak öne çıkmaktadır.

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AKUT ÜST SOLUNUM YOLU ENFEKSİYONU VE KAS-İSKELET SİSTEMİ YAKINMALARI OLAN ÇOCUKLARDA KREATİN KİNAZ YÜKSEKLİĞİNİN SIKLIĞI, ŞİDDETİ VE EŞ ZAMANLI LABORATUVAR BELİRTEÇLERİ: RETROSPEKTİF KOHORT ÇALIŞMASI

FREQUENCY, SEVERITY, AND CONCURRENT LABORATORY MARKERS OF CREATINE KINASE ELEVATION IN CHILDREN WITH ACUTE UPPER RESPIRATORY TRACT INFECTIONS AND MUSCULOSKELETAL COMPLAINTS: A RETROSPECTIVE COHORT STUDY

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ÖZET

Amaç: Kas-iskelet sistemi yakınmalarının akut üst solunum yolu enfeksiyonlarına (ÜSYE) eşlik ettiği çocuklarda kreatin kinaz (CK) sıklıkla ölçülmektedir. Ağır biyokimyasal CK yüksekliğinin sıklığı ve eş zamanlı ölçülen laboratuvar değişkenlerinin bu olguları ne ölçüde ayırt edebildiği yeterince tanımlanmamıştır. Bu çalışmada CK anormalliklerinin sıklığı ve şiddeti tanımlanmış ve çok yüksek CK ile ilişkili laboratuvar belirteçleri araştırılmıştır. **Yöntem:** Bu retrospektif, başvuru düzeyindeki kohort; klinik olarak akut ÜSYE tanısı konulan, eş zamanlı kas-iskelet sistemi yakınmaları bulunan ve CK ölçümü yapılan 1354 pediatrik başvuruyu içermiştir. CK, cinsiyete özgü normal üst sınırlar (NÜS) kullanılarak değerlendirilmiştir. Başvurular CK normal (CK ≤ NÜS), CK yüksek (CK > NÜS ancak çok yüksek eşiğini karşılamayan) veya çok yüksek CK (CK >1000 U/L ya da CK ≥5 × NÜS) olarak sınıflandırılmıştır. Laboratuvar değişkenleri yanlış keşif oranı düzeltmesi kullanılarak gruplar arasında karşılaştırılmıştır. Çok yüksek CK'yi ayırt etme performansı ROC analizleri ve keşifsel lojistik regresyon ile değerlendirilmiştir. **Bulgular:** CK 1212 başvuruda (%89,5) normal, 80 başvuruda (%5,9) yüksek ve 62 başvuruda (%4,6) çok yüksek bulunmuştur. Üç grupta medyan AST sırasıyla 27, 46 ve 115 IU/L; medyan ALT 13,0, 19,5 ve 40,0 IU/L; medyan LDH ise 242, 288 ve 378 U/L'dir. CK şiddeti arttıkça lökosit ve nötrofil sayıları azalmıştır. Çok yüksek CK, yüksek CK ile doğrudan karşılaştırıldığında en güçlü ayırt ediciliği AST göstermiştir (eğri altındaki alan [EAA], 0,919; %95 güven aralığı [GA], 0,862-0,965). Veri seti içinde türetilen AST >72 IU/L eşiği %83,6 duyarlılık ve %90,4 özgüllük sağlamıştır. CK anormalliği bulunan başvurularla sınırlı keşifsel tam-vaka modelinde (n=121; 51 çok yüksek olay), AST çok yüksek CK ile ilişkisini sürdürmüş (iki kat artış başına düzeltilmiş olasılıklar oranı, 34,24; %95 GA, 9,26-126,63; p<0,001), lökosit sayısı, yaş ve cinsiyet ise ilişkili bulunmamıştır. **Sonuç:** CK ölçümü yapılan başvuruların yaklaşık yirmide biri çok yüksek CK için bileşik eşiği karşılamıştır. AST, çok yüksek CK'nin en güçlü eş zamanlı laboratuvar ayırıcısı olmuş; ALT ve LDH ek bilgi sağlamıştır. Bu bulgular, doğrulanmış test öncesi öngördürücülerden ziyade eş zamanlı laboratuvar ilişkilerini tanımlamaktadır; veri seti içinde türetilen eşiklerin harici ve prospektif olarak doğrulanması gerekmektedir.

Anahtar Kelimeler: kreatin kinaz; solunum yolu enfeksiyonları; kas-iskelet sistemi yakınmaları; AST; hiperCKemi; ağır biyokimyasal CK yüksekliği; çocuk

ABSTRACT

Background/Objectives: Creatine kinase (CK) is frequently measured when musculoskeletal complaints accompany acute upper respiratory tract infections (URTIs) in children. The frequency of severe biochemical CK elevation and the extent to which concurrently measured laboratory variables

distinguish these cases are not well characterized. This study described the frequency and severity of CK abnormalities and explored laboratory markers associated with very high CK. **Methods:** This retrospective encounter-level cohort included 1354 pediatric encounters with clinically diagnosed acute URTI, concomitant musculoskeletal complaints, and CK measurement. CK was evaluated using sex-specific upper limits of normal (ULNs). Encounters were categorized as CK normal (CK ≤ ULN), CK elevated (CK > ULN but not meeting the very-high threshold), or very high CK (CK >1000 U/L or CK ≥5 × ULN). Laboratory variables were compared across groups with false-discovery-rate correction. Receiver operating characteristic analyses and exploratory logistic regression evaluated discrimination of very high CK. **Results:** CK was normal in 1212 encounters (89.5%), elevated in 80 (5.9%), and very high in 62 (4.6%). Median AST was 27, 46, and 115 IU/L across the three groups; median ALT was 13.0, 19.5, and 40.0 IU/L; and median LDH was 242, 288, and 378 U/L, respectively. Leukocyte and neutrophil counts decreased across increasing CK severity. When very high CK was compared specifically with elevated CK, AST showed the strongest discrimination (area under the curve [AUC], 0.919; 95% confidence interval [CI], 0.862-0.965). An internally derived AST threshold >72 IU/L had 83.6% sensitivity and 90.4% specificity. In an exploratory complete-case model restricted to CK-abnormal encounters (n=121; 51 very-high events), AST remained associated with very high CK (adjusted odds ratio per doubling, 34.24; 95% CI, 9.26-126.63; p<0.001), whereas leukocyte count, age, and sex were not. **Conclusions:** Approximately one in twenty CK-tested encounters met the composite threshold for very high CK. AST was the strongest concurrent laboratory discriminator of very high CK, with ALT and LDH providing additional information. These findings describe simultaneous laboratory associations rather than validated pretest predictors; the internally derived thresholds require external prospective validation.

Keywords: creatine kinase; respiratory tract infections; musculoskeletal complaints; AST; hyperCKemia; severe biochemical CK elevation; child

1. INTRODUCTION

Creatine kinase (CK) is a widely used biochemical marker of skeletal muscle injury. During acute infections, CK elevation may occur in association with systemic inflammatory responses, infection-related muscle injury, fever, reduced oral intake, and metabolic stress, with abnormalities ranging from mild and transient elevations to marked biochemical evidence of muscle injury. Interpretation of CK concentrations in children can be challenging because CK is influenced by several physiological and clinical factors, including age, sex, pubertal development, muscle mass, physical activity, trauma, intramuscular injections, and analytical methodology [1–3].

Although transient CK elevation may accompany an acute infectious illness, persistent or recurrent hyperCKemia, progressive muscle weakness, delayed motor development, or a family history suggestive of neuromuscular disease warrants consideration of an underlying muscular, metabolic, or genetic disorder [4–6]. Distinguishing transient infection-associated CK elevation from findings that require further investigation is therefore an important component of pediatric clinical assessment.

Acute muscle involvement following respiratory infections is particularly well recognized in benign acute childhood myositis (BACM), which most commonly occurs after influenza or other respiratory viral infections and typically presents with abrupt bilateral calf pain and difficulty walking [7–11]. CK concentrations may be markedly elevated in BACM despite its generally self-limiting clinical course. However, the magnitude of CK elevation alone does not establish the etiology of muscle injury or determine the presence of renal, electrolyte, or other systemic complications. Moreover, much of the existing pediatric literature has focused on selected cohorts with established BACM, viral myositis, or rhabdomyolysis rather than the broader spectrum of children presenting with respiratory infection and musculoskeletal complaints in routine clinical practice.

Rhabdomyolysis represents the severe end of the acute skeletal muscle injury spectrum; however, a universally accepted biochemical definition remains lacking. CK concentrations >1000 U/L or ≥5 times the upper limit of normal (ULN) are commonly used biochemical thresholds [12–14]. Nevertheless, these thresholds should be interpreted together with the clinical presentation, urine findings, kidney

function, electrolyte abnormalities, and temporal evolution. Accordingly, when these additional clinical criteria are unavailable, particularly in retrospective datasets, the more conservative term “very high CK” or “severe biochemical CK elevation” is preferable to assigning a diagnosis of rhabdomyolysis based on CK concentration alone.

Other routinely measured laboratory variables may provide additional information about the biochemical pattern accompanying marked CK elevation. Aspartate aminotransferase (AST), alanine aminotransferase (ALT), and lactate dehydrogenase (LDH) may increase during skeletal muscle injury, whereas infection-associated myositis has also been associated with changes in leukocyte, neutrophil, and platelet counts [9,10]. However, the extent to which these concurrently measured laboratory variables distinguish very high CK from milder CK elevation has not been well characterized in a broader pediatric population undergoing CK testing during acute URTI with musculoskeletal complaints. Importantly, such associations should be regarded as concurrent biochemical relationships rather than evidence that these markers independently predict subsequent CK elevation.

Therefore, the present study aimed to characterize the spectrum of CK abnormalities in children with acute URTI and concomitant musculoskeletal complaints who underwent CK measurement in routine clinical practice. Specifically, we sought to (1) determine the frequency and severity distribution of CK abnormalities; (2) compare demographic and laboratory characteristics among CK-normal, CK-elevated, and very-high-CK groups; and (3) explore the ability of concurrently measured laboratory variables to discriminate very high CK from less severe CK abnormalities.

2. MATERİALS AND METHODS

2.1. Study Design and Setting

This retrospective, single-center, encounter-level cohort study was conducted in the Department of Pediatrics at Hisar Hospital Intercontinental, Istanbul, Türkiye. Routinely collected electronic health record and laboratory information system data were reviewed for pediatric encounters between January 2016 and June 2026. Eligible encounters involved a clinically diagnosed acute upper respiratory tract infection (URTI), concomitant musculoskeletal complaints, and serum creatine kinase (CK) measurement obtained as part of routine clinical evaluation. No study-specific diagnostic, laboratory, or therapeutic procedures were performed. The study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations [19].

2.2. Study Population

The final analytical cohort comprised 1354 eligible pediatric encounters. Encounters were included if all of the following criteria were met: (1) age >3 months and <19 years; (2) encounter date between January 2016 and June 2026; (3) clinician-diagnosed acute URTI; (4) concomitant musculoskeletal complaints; and (5) a valid serum CK measurement obtained during the same clinical encounter. Encounters not meeting these criteria were excluded.

The diagnosis of acute URTI was based on clinician assessment and clinician-assigned diagnoses documented in the source medical record. Microbiological confirmation was not required and was not systematically available. Accordingly, the study population represents clinically diagnosed acute URTI rather than microbiologically confirmed viral infection.

The analytical dataset did not contain a structured free-text symptom field that permitted retrospective reconstruction of the specific musculoskeletal indication for CK measurement. Eligibility for the musculoskeletal-complaint criterion was therefore based on the predefined clinical construction of the source cohort. Because stable patient-level identifiers were unavailable in the analytical dataset, the unit of analysis was the clinical encounter. Repeated encounters involving the same child could not be reliably identified or excluded.

2.3. Data Collection and Data Processing

Extracted variables included age, sex, CK, aspartate aminotransferase (AST), alanine aminotransferase (ALT), lactate dehydrogenase (LDH), quantitative C-reactive protein (CRP), leukocyte count, absolute neutrophil count, absolute lymphocyte count, hemoglobin concentration, and platelet count.

Laboratory measurements were recorded as follows: CK and LDH in U/L; AST and ALT in IU/L; CRP in mg/dL; leukocyte, neutrophil, lymphocyte, and platelet counts in $\times 10^3/\mu L$; and hemoglobin in g/dL. When duplicate representations of the same analyte result occurred within an exported data field, the first valid result was retained according to the prespecified data-cleaning procedure. All included encounters had an available CK measurement. For measurements reported below an analytical detection limit, a value corresponding to one-half of the reported detection limit was assigned for statistical analysis.

2.4. CK Reference Limits and Severity Classification

Because CK concentrations vary with sex, age, muscle mass, population characteristics, physical activity, and analytical methodology, CK values were standardized relative to prespecified sex-specific upper limits of normal (ULNs) [1]. For participants aged >3 months, the reference intervals reported by Mayo Clinic Laboratories were used: 39–308 U/L for males and 26–192 U/L for females [2]. The CK/ULN ratio was calculated by dividing the measured CK concentration by the corresponding sex-specific ULN.

For descriptive characterization of the CK distribution, values were classified a priori as below the sex-specific reference interval, within the reference interval, borderline elevation (>1 to <1.5 × ULN), moderate elevation (≥1.5 to <5 × ULN), severe elevation (≥5 to <10 × ULN), or marked elevation (≥10 × ULN).

For the principal severity analyses, encounters were categorized into three mutually exclusive groups: CK normal (CK ≤ ULN), CK elevated (CK > ULN without meeting the very-high criterion), and very high CK (CK >1000 U/L or CK ≥5 × ULN). The latter definition incorporated two biochemical thresholds frequently used in the rhabdomyolysis literature [12–14]. This classification was intended solely to characterize biochemical severity and was not considered sufficient to establish a clinical diagnosis of rhabdomyolysis in the absence of corresponding clinical, renal, urinary, and electrolyte information.

2.5. Study Outcomes

The primary descriptive outcome was the frequency of CK elevation above the sex-specific ULN. Secondary descriptive outcomes included the frequencies of CK ≥1.5 × ULN, CK ≥5 × ULN, CK ≥10 × ULN, CK >1000 U/L, and the composite very-high-CK criterion (CK >1000 U/L or CK ≥5 × ULN).

The principal exploratory outcome was membership in the very-high-CK group. Concurrently measured laboratory variables were compared across CK severity groups and were further evaluated for their ability to discriminate very high CK from elevated but non-very-high CK. These analyses were intended to characterize concurrent biochemical associations rather than to develop or validate a prospective clinical prediction model.

2.6. Statistical Analysis

Continuous variables were summarized as medians and interquartile ranges (IQRs) because of their non-normal distributions. Categorical variables were presented as frequencies and percentages. Wilson 95% confidence intervals (CIs) were calculated for the principal CK frequency estimates.

Continuous variables were compared across the three CK severity groups using the Kruskal–Wallis test, whereas categorical variables were compared using the chi-squared test or an exact test, as appropriate. Pairwise comparisons of the very-high-CK group with the CK-normal and CK-elevated groups were performed using the Mann–Whitney U test. To reduce the risk of false-positive findings arising from multiple laboratory comparisons, Benjamini–Hochberg false-discovery-rate (FDR) correction was applied within the prespecified families of laboratory comparisons.

Receiver operating characteristic (ROC) curve analyses were used to quantify the concurrent discrimination of very high CK by routinely measured laboratory variables. The principal ROC analysis compared very-high-CK encounters with elevated but non-very-high-CK encounters, thereby focusing specifically on encounters with abnormal CK concentrations. Areas under the curve (AUCs) with stratified-bootstrap 95% CIs were calculated. For descriptive purposes, internally derived thresholds

were identified using the Youden index, and their corresponding sensitivity and specificity were reported. Because threshold selection and performance assessment were conducted in the same dataset, these cutoffs were considered exploratory and were not interpreted as externally validated clinical decision thresholds.

Two exploratory multivariable logistic regression models were constructed using complete observations. Model 1 compared very high CK with all other encounters, whereas Model 2 compared very high CK specifically with elevated but non-very-high CK. Both models included $\log_2$-transformed AST, $\log_2$-transformed leukocyte count, age per 5-year increase, and sex. AST and leukocyte count were selected as parsimonious representatives of muscle-associated enzyme elevation and hematological change. ALT was not entered simultaneously with AST because of biological and statistical overlap, whereas LDH was excluded from multivariable modeling because of its limited availability (257 encounters). Odds ratios for AST and leukocyte count therefore represent the change in odds associated with each doubling of the corresponding laboratory value. Model discrimination was summarized using the AUC. Because these models were exploratory and internally evaluated, their performance was not interpreted as evidence of validated predictive ability.

Spearman rank correlation coefficients were calculated between CK and concurrently measured laboratory variables, with FDR correction applied across the correlation analyses. CK data were complete for all included encounters. Other analyses were performed using available observations, without missing-data imputation.

All statistical tests were two-sided, and $p < 0.05$ was considered statistically significant. Analyses were performed using Python version 3.13.5, SciPy version 1.17.0, statsmodels version 0.14.6, and scikit-learn.

2.7. Ethical Considerations

The study protocol was approved by the Ethics Committee of Hisar Hospital Intercontinental on 29 June 2026 (approval no. 26/75). The requirement for individual informed consent was waived because of the retrospective design and the use of de-identified, routinely collected clinical data. The study was conducted in accordance with the Declaration of Helsinki and applicable data-protection regulations.

3. RESULTS

3.1. Cohort Characteristics and CK Distribution

The final analytical cohort comprised 1354 pediatric encounters involving clinically diagnosed acute URTI, concomitant musculoskeletal complaints, and CK measurement. The median age was 6.9 years (IQR, 4.0–10.5), and 828 encounters (61.2%) involved male patients.

The median CK concentration was 92 U/L (IQR, 66–139), with a markedly right-skewed distribution ranging from 15 to 23,625 U/L. CK exceeded the sex-specific ULN in 142 encounters (10.5%; 95% CI, 9.0%–12.2%). CK was ≥1.5 × ULN in 104 encounters (7.7%; 95% CI, 6.4%–9.2%), ≥5 × ULN in 53 (3.9%; 95% CI, 3.0%–5.1%), and ≥10 × ULN in 23 (1.7%; 95% CI, 1.1%–2.5%). CK exceeded 1000 U/L in 60 encounters (4.4%; 95% CI, 3.5%–5.7%), and 62 encounters (4.6%; 95% CI, 3.6%–5.8%) met the composite criterion for very high CK (Table 1).

Table 1. Distribution of CK categories and additional biochemical thresholds (n = 1354).

CK category or threshold	n	%	95% CI
Below the sex-specific reference interval	35	2.6	1.9-3.6
Within the sex-specific reference interval	1177	86.9	85.0-88.6
Borderline elevation (> 1 to < 1.5 × ULN)	38	2.8	2.1-3.8
Moderate elevation (≥ 1.5 to < 5 × ULN)	51	3.8	2.9-4.9
Severe elevation (≥ 5 to < 10 × ULN)	30	2.2	1.6-3.1

CK category or threshold	n	%	95% CI
Marked elevation (≥ 10 × ULN)	23	1.7	1.1-2.5
CK > ULN	142	10.5	9.0-12.2
CK ≥ 1.5 × ULN	104	7.7	6.4-9.2
CK ≥ 5 × ULN	53	3.9	3.0-5.1
CK ≥ 10 × ULN	23	1.7	1.1-2.5
CK > 1000 U/L	60	4.4	3.5-5.7
CK > 1000 U/L or CK ≥ 5 × ULN	62	4.6	3.6-5.8

Table note: The first six rows represent mutually exclusive CK categories and total 1354 encounters. The remaining rows represent overlapping biochemical thresholds. Confidence intervals were calculated using the Wilson method. CK ≥5 × ULN was considered a threshold for severe biochemical CK elevation but was not interpreted as a clinical diagnosis of rhabdomyolysis without compatible clinical findings and supporting urinary, renal, and electrolyte assessments. CK, creatine kinase; ULN, upper limit of normal; CI, confidence interval.

3.2. Characteristics According to CK Severity

The three mutually exclusive severity groups comprised 1212 CK-normal encounters (89.5%), 80 CK-elevated encounters (5.9%), and 62 very-high-CK encounters (4.6%). Median age was 7.2 years (IQR, 3.8–10.9), 5.7 years (IQR, 4.4–7.8), and 6.8 years (IQR, 5.4–8.1), respectively, with no significant overall difference in continuous age across groups (p = 0.186). Male patients accounted for 60.8%, 56.3%, and 74.2% of the respective groups (p = 0.070).

In contrast, the distribution across predefined age categories differed significantly among CK severity groups (p < 0.001). No very-high-CK encounters occurred in the youngest age category, whereas 58.1% of the very-high-CK group involved children aged 6–11 years (Table 2).

Median CK concentrations increased substantially across the three groups, from 86 U/L (IQR, 64–119) in the CK-normal group to 404 U/L (IQR, 319–626) in the CK-elevated group and 2314 U/L (IQR, 1568–3668) in the very-high-CK group. The corresponding median CK/ULN ratios were 0.34, 1.56, and 8.94, respectively.

Table 2. Demographic and laboratory characteristics across the three CK severity groups.

Characteristic	CK normal (n = 1212)	CK elevated (n = 80)	Very high CK (n = 62)	Global p-value	FDR p: very high vs elevated
Age, years	7.2 (3.8-10.9)	5.7 (4.4-7.8)	6.8 (5.4-8.1)	0.186	—
Male sex, n (%)	737 (60.8)	45 (56.3)	46 (74.2)	0.070	—
Age group, n (%)				<0.001	—
>3 months to <2 years	116 (9.6)	4 (5.0)	0 (0.0)		
2-5 years	388 (32.0)	40 (50.0)	22 (35.5)		
6-11 years	487 (40.2)	26 (32.5)	36 (58.1)		
12-18 years	221 (18.2)	10 (12.5)	4 (6.5)		

Characteristic	CK normal (n = 1212)	CK elevated (n = 80)	Very high CK (n = 62)	Global p-value	FDR p: very high vs elevated
CK, U/L	86 (64-119)	404 (319-626)	2314 (1568-3668)	—	—
CK/ULN ratio	0.34 (0.25-0.47)	1.56 (1.25-2.19)	8.94 (5.51-13.32)	—	—
AST, IU/L	27 (22–34) [n=1082]	46 (35–60) [n=73]	115 (85–163) [n=55]	<0.001	<0.001
ALT, IU/L	13.0 (11.0–18.0) [n=1041]	19.5 (16.0–28.0) [n=70]	40.0 (24.0–57.0) [n=53]	<0.001	<0.001
LDH, U/L	242 (214–282) [n=213]	288 (262–326) [n=24]	378 (307–456) [n=20]	<0.001	0.011
CRP, mg/dL	0.94 (0.29–4.80) [n=1062]	0.44 (0.17–2.65) [n=63]	0.51 (0.29–2.23) [n=55]	0.024	0.735
Leukocyte count, ×10³/µL	8.27 (6.37–11.21) [n=1170]	5.70 (4.00–7.71) [n=76]	4.32 (3.13–5.72) [n=57]	<0.001	0.009
Neutrophil count, ×10³/µL	4.33 (2.84–6.89) [n=1169]	2.23 (1.19–3.54) [n=75]	1.40 (0.94–2.56) [n=58]	<0.001	0.013
Lymphocyte count, ×10³/µL	2.57 (1.71–3.69) [n=1169]	2.62 (1.95–3.39) [n=76]	2.06 (1.62–2.59) [n=58]	0.017	0.011
Hemoglobin, g/dL	12.4 (11.6–13.1) [n=1168]	12.3 (11.8–13.0) [n=76]	12.5 (12.0–13.1) [n=59]	0.397	0.240
Platelet count, ×10³/µL	287 (231–353) [n=1170]	218 (172–296) [n=75]	208 (182–270) [n=58]	<0.001	0.377

Table note: Values are median (IQR), n (%), or median (IQR) [available n], as appropriate. CK normal was defined as CK ≤ the sex-specific ULN. CK elevated was defined as CK > ULN without meeting the composite very-high threshold. Very high CK was defined as CK >1000 U/L or CK ≥5 × ULN. Continuous variables were compared using the Kruskal-Wallis test; categorical variables used the chi-squared or exact test. The final column gives Benjamini-Hochberg FDR-adjusted Mann-Whitney U test p-values for the very-high-versus-elevated comparison for laboratory variables. P-values were not calculated for CK and CK/ULN because the groups were defined by CK severity. CK, creatine kinase; ULN, upper limit of normal; AST, aspartate aminotransferase; ALT, alanine aminotransferase; LDH, lactate dehydrogenase; CRP, C-reactive protein; FDR, false discovery rate.

3.3. Concurrent Laboratory Findings

Clear differences in concurrently measured laboratory variables were observed across CK severity groups (Table 2). AST increased progressively from a median of 27 IU/L (IQR, 22–34) in the CK-normal group to 46 IU/L (IQR, 35–60) in the CK-elevated group and 115 IU/L (IQR, 85–163) in the very-high-CK group. Median ALT concentrations were 13.0, 19.5, and 40.0 IU/L, respectively, while median LDH concentrations were 242, 288, and 378 U/L. Differences in AST, ALT, and LDH remained significant after FDR correction (all FDR-adjusted $p < 0.001$).

An inverse pattern was observed for several hematological variables. Median leukocyte counts decreased from 8.27 × 10³/µL in the CK-normal group to 5.70 × 10³/µL in the CK-elevated group and 4.32 × 10³/µL in the very-high-CK group. Corresponding median neutrophil counts were 4.33, 2.23, and

1.40 × 10³/μL. Platelet counts were also lower in the two CK-abnormal groups than in the CK-normal group; however, platelet counts did not differ significantly between the CK-elevated and very-high-CK groups after FDR correction. CRP differed across the three severity groups but did not significantly distinguish very high from elevated CK after correction for multiple comparisons. Hemoglobin concentrations did not differ significantly among groups.

In the direct comparison restricted to encounters with abnormal CK, AST, ALT, LDH, leukocyte count, neutrophil count, and lymphocyte count differed significantly between the CK-elevated and very-high-CK groups after FDR correction. Among these variables, AST demonstrated the greatest separation between the two groups.

3.4. Concurrent Discrimination of Very High CK

Among encounters with abnormal CK, AST demonstrated the strongest concurrent discrimination between very high and elevated CK, with an AUC of 0.919 (95% CI, 0.862–0.965). The internally derived AST threshold of >72 IU/L yielded a sensitivity of 83.6% and specificity of 90.4%.

ALT demonstrated lower discrimination (AUC, 0.802; 95% CI, 0.724–0.874). An internally derived threshold of >21 IU/L yielded 92.5% sensitivity and 57.1% specificity. LDH had an AUC of 0.746 (95% CI, 0.587–0.894); however, this analysis was based on only 44 encounters because of substantial missingness and should therefore be interpreted cautiously.

Leukocyte and neutrophil counts showed limited discrimination between the two CK-abnormal groups (AUCs, 0.651 and 0.633, respectively), while platelet count showed little discriminatory ability (AUC, 0.549). The AST/ALT ratio demonstrated modest discrimination (AUC, 0.704). Full ROC results, including exploratory thresholds, sensitivity, and specificity, are presented in Table 3.

Table 3. Receiver operating characteristic analyses for distinguishing very high CK from elevated CK.

Marker	Analysis n	Very-high events n	AUC	95% CI	Youden threshold	Sensitivity, %	Specificity, %
AST	128	55	0.919	0.862-0.965	>72	83.6	90.4
ALT	123	53	0.802	0.724-0.874	>21	92.5	57.1
LDH	44	20	0.746	0.587-0.894	>375	55.0	95.8
Leukocyte count	133	57	0.651	0.553-0.740	<5.72	75.4	50.0
Neutrophil count	133	58	0.633	0.541-0.732	<1.92	69.0	54.7
Lymphocyte count	134	58	0.639	0.549-0.728	<2.61	77.6	51.3
Platelet count	133	58	0.549	0.453-0.645	<291	87.9	29.3
AST/ALT ratio	122	53	0.704	0.599-0.798	>2.93	66.0	73.9

Table note: Very high CK was defined as CK >1000 U/L or CK ≥5 × ULN; elevated CK was CK > ULN without meeting the very-high threshold. For leukocyte, neutrophil, lymphocyte, and platelet counts, lower values were treated as the risk direction; thresholds are therefore shown with a less-than sign. Thresholds were selected by the Youden index in the same dataset and are exploratory. Bootstrap confidence intervals used stratified resampling. AUC, area under the receiver operating characteristic curve; CI, confidence interval; AST, aspartate aminotransferase; ALT, alanine aminotransferase; LDH, lactate dehydrogenase.

3.5. Exploratory Multivariable Analyses

In the complete-case analysis comparing very high CK with all other encounters (n = 1178; 51 very-high-CK events), each doubling of AST was associated with substantially higher odds of membership in the very-high-CK group after adjustment for leukocyte count, age, and sex (aOR, 6.57; 95% CI, 4.38–9.86; $p < 0.001$). Conversely, each doubling of leukocyte count was associated with lower odds of very

high CK (aOR, 0.16; 95% CI, 0.08–0.31; $p < 0.001$). Increasing age was also associated with higher odds of very high CK (aOR per 5-year increase, 2.26; 95% CI, 1.23–4.16; $p = 0.009$), whereas sex was not significantly associated. The apparent, in-sample AUC of this exploratory model was 0.978.

In the more restrictive analysis limited to CK-abnormal encounters (n = 121; 51 very-high-CK events), AST remained strongly associated with very high CK after adjustment (aOR per doubling, 34.24; 95% CI, 9.26–126.63; $p < 0.001$). Leukocyte count, age, and sex were not significantly associated with very-high-CK status in this model. The apparent, in-sample model AUC was 0.937 (Table 4).

Table 4. Exploratory multivariable logistic regression analyses of very high CK.

Model	Complete-case n	Very-high events n	Model AUC	Predictor	aOR	95% CI	p-value
Model 1: very high CK vs all other encounters	1178	51	0.978	AST, per doubling	6.57	4.38-9.86	<0.001
Model 1: very high CK vs all other encounters	1178	51	0.978	Leukocyte count, per doubling	0.16	0.08-0.31	<0.001
Model 1: very high CK vs all other encounters	1178	51	0.978	Age, per 5-year increase	2.26	1.23-4.16	0.009
Model 1: very high CK vs all other encounters	1178	51	0.978	Male sex	1.90	0.79-4.59	0.155
Model 2: very high CK vs elevated CK	121	51	0.937	AST, per doubling	34.24	9.26-126.63	<0.001
Model 2: very high CK vs elevated CK	121	51	0.937	Leukocyte count, per doubling	1.43	0.55-3.72	0.463
Model 2: very high CK vs elevated CK	121	51	0.937	Age, per 5-year increase	2.37	0.88-6.38	0.087
Model 2: very high CK vs elevated CK	121	51	0.937	Male sex	1.29	0.36-4.60	0.694

Table note: Model 1 compared very high CK with all remaining encounters. Model 2 compared very high CK with elevated CK only. Both models included log2-transformed AST and leukocyte count, age per 5-year increase, and sex. Odds ratios for AST and leukocyte count represent each doubling of the value. Very high CK was defined as CK >1000 U/L or CK ≥5 × ULN. These exploratory models evaluated concurrent association and discrimination, not temporal prediction. AUC, area under the receiver operating characteristic curve; aOR, adjusted odds ratio; CI, confidence interval; AST, aspartate aminotransferase.

Because CK and the evaluated laboratory variables were measured concurrently and model performance was assessed in the same dataset in which the models were fitted, these analyses characterize cross-sectional association and discrimination rather than temporal or externally validated prediction.

3.6. Correlations with Concurrent Laboratory Measurements

Across the overall cohort, CK showed positive correlations with AST (Spearman's $\rho = 0.350$), ALT ($\rho = 0.256$), and LDH ($\rho = 0.350$). Inverse correlations were observed between CK and CRP ($\rho = -0.265$), leukocyte count ($\rho = -0.232$), neutrophil count ($\rho = -0.272$), and platelet count ($\rho = -0.101$). These associations remained statistically significant after FDR correction.

Correlations with lymphocyte count and hemoglobin were weak (both $\rho = 0.080$) and were not considered clinically meaningful despite their statistical estimates (Supplementary Table S1).

Supplementary Table S1. Spearman correlations between creatine kinase and concurrent laboratory measurements.

Laboratory variable	Available n	Spearman ρ	Unadjusted p-value	FDR-adjusted p-value
AST	1210	0.350	< 0.001	< 0.001
ALT	1164	0.256	< 0.001	< 0.001
LDH	257	0.350	< 0.001	< 0.001
CRP	1180	-0.265	< 0.001	< 0.001
Leukocyte count	1303	-0.232	< 0.001	< 0.001
Absolute neutrophil count	1302	-0.272	< 0.001	< 0.001
Absolute lymphocyte count	1303	0.080	0.004	0.004
Hemoglobin	1303	0.080	0.004	0.004
Platelet count	1303	-0.101	< 0.001	< 0.001

Table note: Spearman rank correlation coefficients were calculated using available observations for each laboratory variable. The Benjamini-Hochberg procedure controlled the false discovery rate across the nine correlation analyses. Values below an analytical reporting limit were assigned one-half of the stated limit. AST, aspartate aminotransferase; ALT, alanine aminotransferase; LDH, lactate dehydrogenase; CRP, C-reactive protein; CK, creatine kinase; FDR, false discovery rate.

4. DİSCUSSİON

In this retrospective encounter-level cohort of children with clinically diagnosed acute URTI, concomitant musculoskeletal complaints, and clinically obtained CK measurements, several important findings emerged. CK exceeded the sex-specific ULN in 10.5% of encounters, whereas 4.6% met the composite criterion for very high CK. Increasing CK severity was accompanied by progressively higher AST, ALT, and LDH concentrations and lower leukocyte and neutrophil counts. Most notably, among encounters in which CK was already abnormal, AST demonstrated the strongest concurrent discrimination between very high and less pronounced CK elevation. This relationship remained prominent after adjustment for age, sex, and leukocyte count. However, because CK and the evaluated laboratory variables were measured concurrently, these findings characterize biochemical association and discrimination rather than temporal prediction.

The frequency of very high CK should be interpreted within the specific sampling framework of this study. The observed 4.6% frequency does not represent the population prevalence of severe CK elevation among all children with URTI. Every included encounter involved both musculoskeletal complaints and a clinical decision to measure CK, resulting in a symptom-selected and test-selected population. Accordingly, our findings describe the spectrum and diagnostic yield of CK abnormalities among children in whom muscle involvement was sufficiently suspected to prompt CK testing. Nevertheless, approximately one in twenty CK-tested encounters met a biochemical threshold commonly associated with substantial skeletal muscle injury, indicating that marked CK elevation can occur within the broader spectrum of musculoskeletal manifestations accompanying acute respiratory illness.

Previous pediatric literature has predominantly focused on clinically defined BACM, influenza-associated myositis, or established rhabdomyolysis rather than the broader population of children undergoing CK testing during acute respiratory illness [6–10,18]. BACM typically occurs in school-aged children following a viral respiratory illness and is characterized by acute bilateral calf pain, gait

disturbance, and elevated CK, with influenza representing one of the most frequently identified viral triggers [6–10]. Most cases follow a self-limited course, although marked CK elevation and occasional progression to rhabdomyolysis have been reported [7,9,18]. Interestingly, the predominance of children aged 6–11 years and the relatively high proportion of males in our very-high-CK group resemble the demographic pattern described in BACM cohorts [6,8,9]. However, our population should not be considered a BACM cohort because characteristic symptom localization and systematic microbiological confirmation were unavailable.

The broader relationship between infection and severe skeletal muscle injury is also supported by the pediatric rhabdomyolysis literature. A recent systematic review and meta-analysis involving more than 10,000 children identified infections as the most frequent reported etiology of pediatric rhabdomyolysis, accounting for approximately 40% of cases [13]. Viral rhabdomyolysis has also been described in pediatric hospital cohorts, although the risk of renal complications varies considerably according to population characteristics, etiology, and case definition [19,20]. These observations support a biological continuum ranging from transient infection-associated CK elevation and BACM to more substantial muscle injury. The present study extends this literature by characterizing CK severity across a broader CK-tested clinical population without requiring a pre-existing diagnosis of myositis or rhabdomyolysis.

A major finding was the strong relationship between AST and CK severity. Although AST is routinely interpreted within hepatic biochemical assessment, it is also present in skeletal muscle and may increase substantially during muscle injury. Aminotransferase abnormalities, particularly AST elevation, are well described in rhabdomyolysis, and AST concentrations have been reported to decrease in parallel with CK as muscle injury resolves [14]. Contemporary reviews of pediatric rhabdomyolysis similarly emphasize that AST and ALT abnormalities may accompany skeletal muscle breakdown and should not automatically be interpreted as evidence of primary hepatic injury [12]. Consistent with these observations, AST increased markedly across CK severity categories in the present study, from a median of 27 IU/L in CK-normal encounters to 115 IU/L in the very-high-CK group.

The analysis restricted to children with abnormal CK provides an additional perspective. Rather than relying on the relatively straightforward distinction between normal and markedly abnormal CK, this analysis examined whether concurrently available laboratory variables could distinguish very high CK from less pronounced CK elevation. AST demonstrated an AUC of 0.919 for this comparison, substantially exceeding the discrimination observed for the other evaluated laboratory variables. These results suggest that AST carries information about the biochemical severity of concurrent muscle injury even after CK abnormality is established.

The internally derived AST threshold of >72 IU/L yielded a sensitivity of 83.6% and specificity of 90.4% for distinguishing very high from elevated CK. However, this finding requires particularly cautious interpretation. The threshold was selected and evaluated using the same retrospective dataset and is therefore susceptible to optimism. Furthermore, AST and CK were measured during the same clinical encounter, and the sequence of test ordering and result availability could not be reconstructed. Thus, >72 IU/L should not be regarded as a validated trigger for CK measurement or a clinical decision threshold. Rather, it represents a hypothesis-generating cutoff that warrants evaluation in an independent cohort.

The exploratory multivariable analysis reinforces this interpretation. Among CK-abnormal encounters, each doubling of AST was associated with markedly higher adjusted odds of belonging to the very-high-CK group. However, the large effect estimate, wide confidence interval, and high apparent model AUC should not be interpreted as evidence of independent causal or prospective predictive value. AST and CK are biologically related manifestations of skeletal muscle injury, and the model was developed and evaluated within the same dataset without internal cross-validation. Accordingly, the primary value of this analysis is descriptive: the association between AST and CK severity remained prominent even when the analysis was restricted to encounters with an already abnormal CK result.

ALT and LDH also increased across CK severity groups, but their discriminatory performance was weaker than that of AST. ALT demonstrated relatively high sensitivity but limited specificity at its internally selected threshold, whereas LDH estimates were constrained by substantial missingness. The

AST/ALT ratio provided only modest discrimination. Taken together, these findings suggest that absolute AST concentration may be more informative than ALT, LDH, or the AST/ALT ratio for characterizing concurrent biochemical CK severity in this clinical context. Nevertheless, none of these markers should be considered a substitute for direct CK measurement.

An additional finding was the progressive decline in leukocyte and neutrophil counts with increasing CK severity. Similar hematological patterns have been reported in BACM and influenza-associated myositis cohorts [8–10]. However, leukocyte and neutrophil counts showed substantially weaker discrimination between the two CK-abnormal groups than AST, and leukocyte count was no longer significantly associated with very-high-CK status in the restricted multivariable analysis. CRP and platelet count likewise differentiated CK-normal from CK-abnormal encounters more clearly than they differentiated biochemical severity among CK-abnormal encounters. These findings suggest that hematological changes may accompany the broader infection-associated muscle-injury phenotype but have limited ability to grade the severity of CK elevation once hyperCKemia is established. Because microbiological testing was not systematically available, these hematological patterns cannot be attributed specifically to influenza or any other viral pathogen.

The distinction between very high biochemical CK and clinical rhabdomyolysis is particularly important. Definitions of rhabdomyolysis remain heterogeneous, although CK >1000 U/L and CK ≥5 × ULN are among the most frequently used biochemical criteria [11,12,17]. However, contemporary reviews and consensus recommendations emphasize that CK elevation should be interpreted together with the clinical syndrome, renal function, electrolyte abnormalities, urine findings, hydration status, underlying etiology, and temporal evolution [11–13,21]. Pediatric studies further demonstrate that acute kidney injury is an important complication of rhabdomyolysis and cannot be inferred from CK concentration alone [13,19,20]. Indeed, the recent pediatric meta-analysis reported a pooled AKI frequency of approximately 21% among children with rhabdomyolysis [13].

The present dataset did not contain sufficiently complete information on serum creatinine, potassium, bicarbonate, urinalysis, urine myoglobin, hydration status, serial CK measurements, treatment, or clinical outcomes. Consequently, the 62 encounters meeting the composite biochemical threshold were deliberately classified as having “very high CK” rather than confirmed rhabdomyolysis. This conservative terminology prevents biochemical severity from being conflated with a clinical diagnosis and represents an important distinction when interpreting retrospective laboratory-based data.

From a clinical perspective, the present findings support contextual interpretation rather than a stand-alone laboratory rule. In a child presenting with an acute respiratory illness and musculoskeletal complaints, concurrent elevation of CK and AST should raise consideration of skeletal muscle involvement and may help prevent misattribution of aminotransferase abnormalities solely to hepatic disease [12,14]. Nevertheless, evaluation of substantial CK elevation should include assessment of muscle symptoms, neurological findings, hydration, renal function, electrolytes, urine abnormalities, and CK trajectory [12,13,19–21]. Conversely, persistent or recurrent hyperCKemia, progressive or proximal weakness, delayed motor development, calf hypertrophy, exercise intolerance, relevant family history, or otherwise unexplained aminotransferase elevation should prompt consideration of an underlying neuromuscular or metabolic disorder [3–5,22].

4.1. Strengths and Limitations

This study has several strengths. It included a relatively large pediatric cohort and characterized CK across a broad spectrum of CK-tested encounters rather than restricting inclusion to children already diagnosed with BACM, viral myositis, or rhabdomyolysis. CK values were standardized using sex-specific reference limits, multiple biochemical severity thresholds were examined, and mutually exclusive CK severity groups were directly compared. Importantly, the analyses distinguished between the relatively straightforward comparison of very high versus normal CK and the more clinically informative comparison of very high versus less pronounced CK elevation. Multiple laboratory comparisons were addressed using FDR correction, and ROC-derived thresholds were explicitly treated as exploratory rather than validated clinical cutoffs.

Several limitations should be acknowledged. First, the retrospective, single-center, symptom-selected, and test-selected design limits generalizability and prevents estimation of the prevalence of CK elevation among all children with acute URTI. The results apply specifically to children with musculoskeletal complaints in whom clinicians elected to obtain CK measurements.

Second, detailed clinical phenotyping was unavailable. Information regarding pain location and severity, calf involvement, gait disturbance, objective weakness, neurological examination, illness duration, exercise, trauma, intramuscular injections, medication exposure, hydration status, and underlying neuromuscular or metabolic conditions could not be systematically incorporated. Microbiological testing was also not consistently available, precluding pathogen-specific analyses.

Third, stable patient identifiers were unavailable in the analytical dataset. Repeated encounters involving the same child could therefore not be identified or excluded, and encounters were treated as independent observations. If individual children contributed multiple encounters, variance estimates and confidence intervals may have been affected.

Fourth, local analyzer-specific CK reference intervals were unavailable. External sex-specific limits provided a consistent analytical framework but may have introduced some misclassification because pediatric CK concentrations and reference intervals can vary with age, sex, pubertal status, population characteristics, and assay methodology [1,2].

Fifth, sufficiently complete information on renal function, electrolytes, bicarbonate, urinalysis, urine myoglobin, serial CK measurements, hospitalization, treatment, and clinical outcomes was unavailable. Consequently, we could not evaluate confirmed rhabdomyolysis, acute kidney injury, treatment requirements, or the clinical course of children with very high CK [12,13,19–21].

Finally, the evaluated laboratory variables and CK were concurrent measurements rather than temporally ordered predictors. Laboratory missingness varied, particularly for LDH. ROC thresholds were optimized within the same dataset without internal cross-validation or external validation, and the regression models were evaluated using the same data on which they were developed. The high apparent AUCs and large AST effect estimates may therefore overestimate performance. In addition, only 62 encounters met the very-high-CK criterion, and complete-case multivariable analyses included 51 very-high events, limiting model complexity and precision.

4.2. Clinical Implications and Future Research

The present findings identify AST as a strong concurrent biochemical marker of CK severity among children undergoing CK testing during acute URTI accompanied by musculoskeletal complaints. They do not establish AST as a replacement for CK or as a validated trigger for CK measurement. Rather, the findings highlight a clinically recognizable biochemical pattern that may assist in interpreting elevated aminotransferases when skeletal muscle involvement is suspected [12,14].

Prospective multicenter studies should enroll clinically well-characterized children with standardized documentation of musculoskeletal symptoms and examination findings before laboratory results are known. Future investigations should incorporate pathogen testing, renal function, electrolytes, urinalysis, serial CK measurements, treatment, and clinical outcomes. The AST threshold identified in the present study should be evaluated in an independent cohort without data-driven reoptimization. Ultimately, prediction models should focus on clinically actionable outcomes—such as hospitalization, intravenous hydration requirements, acute kidney injury, or prolonged CK elevation—rather than discrimination of one concurrent laboratory abnormality from another.

5. CONCLUSİONS

Among pediatric encounters involving acute URTI, concomitant musculoskeletal complaints, and clinically requested CK measurement, CK exceeded the sex-specific ULN in approximately one in ten encounters, while 4.6% met the composite criterion for very high biochemical CK elevation. AST showed the strongest concurrent discrimination between very high and less pronounced CK elevation, whereas ALT and LDH provided additional but weaker discriminatory information. Lower leukocyte and neutrophil counts accompanied increasing CK severity but contributed limited discrimination

among CK-abnormal encounters. These findings support consideration of skeletal muscle involvement when marked AST elevation occurs in children with acute respiratory illness and musculoskeletal symptoms, while emphasizing that AST should not replace direct CK measurement. The identified associations and internally derived thresholds should be regarded as exploratory rather than predictive or diagnostic, and prospective external validation against clinically meaningful outcomes is required.

DECLARATİONS

Ethics approval and consent to participate

The study was conducted in accordance with the principles of the Declaration of Helsinki and approved by the Institutional Ethics Committee of Hisar Hospital Intercontinental (approval date: 29 June 2026; approval number: 26/75). Because of the retrospective design and use of de-identified patient data, the requirement for informed consent was waived by the ethics committee.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

YN conceived the study. YN designed the methodology. YN collected and curated the data. YN performed the statistical analyses and prepared the tables. YN drafted the manuscript. YN critically revised the manuscript for important intellectual content. YN supervised the study and contributed to interpretation of the data. author read and approved the final manuscript.

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ORNİTHOGALUM TÜRLERİNDE YAĞ ASİDİ PROFİLLERİNİN BİYOKİMYASAL VE KEMOTAKSONOMİK AÇIDAN DEĞERLENDİRİLMESİ

BIOCHEMICAL AND CHEMOTAXONOMIC EVALUATION OF FATTY ACID PROFILES IN ORNITHOGALUM SPECIES

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ÖZET

Ornithogalum L. (Asparagaceae), Avrupa, Afrika ve Batı Asya'da yayılış gösteren, morfolojik ve ekolojik açıdan geniş çeşitlilik sergileyen bir bitki cinsidir. Türlerin biyokimyasal özelliklerinin ortaya konulması, fizyolojik adaptasyonların anlaşılması ve taksonomik ilişkilerin desteklenmesi açısından önem taşımaktadır. Bu çalışmada, farklı *Ornithogalum* türlerinin yağ asidi profillerinin biyokimyasal çeşitlilik ve kemotaksonomik potansiyel açısından değerlendirilmesi amaçlanmıştır. Literatürde ve deneysel analizlerde bildirilen yağ asidi kompozisyonları incelendiğinde, palmitik asit (C16:0), stearik asit (C18:0), oleik asit (C18:1), linoleik asit (C18:2) ve α-linolenik asidin (C18:3) birçok türde öne çıkan temel yağ asitleri olduğu görülmektedir. Bununla birlikte, bu bileşenlerin göreceli oranları türlere ve bitki organlarına bağlı olarak önemli farklılıklar göstermektedir. Doymuş ve doymamış yağ asitlerinin dağılımındaki bu farklılıkların; sıcaklık, rakım, su stresi ve toprak özellikleri gibi çevresel koşullarla ilişkili olabileceği bildirilmektedir. Türler arasında gözlenen bu karakteristik yağ asidi profilleri, yakın akraba taksonların ayırt edilmesinde ve tür sınırlarının değerlendirilmesinde potansiyel kemotaksonomik belirteçler sunmaktadır.

Anahtar Kelimeler: *Ornithogalum,* yağ asitleri, GC-MS, lipit profili, kemotaksonomi, biyokimyasal çeşitlilik.

ABSTRACT

Ornithogalum L. (Asparagaceae) is a genus of plants distributed across Europe, Africa, and Western Asia, exhibiting wide morphological and ecological diversity. Understanding the biochemical characteristics of these species is crucial for comprehending physiological adaptations and supporting taxonomic relationships. This study aimed to evaluate the fatty acid profiles of different *Ornithogalum* species in terms of biochemical diversity and chemotaxonomic potential. Examination of fatty acid compositions reported in literature and verified through experimental analyses reveals that palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), and α-linolenic acid (C18:3) are prominent fatty acids in many species. However, the relative proportions of these components show significant differences depending on the species and plant organs. Differences in the distribution of saturated and unsaturated fatty acids are reported to be related to environmental conditions such as temperature, altitude, water stress, and soil characteristics. Furthermore, the characteristic fatty acid profiles observed among species can be considered as potential chemotaxonomic markers in distinguishing closely related taxa and evaluating species boundaries.

Keywords: *Ornithogalum*, fatty acids, GC-MS, lipid profile, chemotaxonomy, biochemical *diversity.*

1. GİRİŞ

Ornithogalum L. cinsi (Asparagaceae), halk arasında 'Akyıldız' adıyla bilinen, genellikle çok yıllık, soğanlı veya rizomlu otsu bitkilerden oluşan geniş bir gruptur (Bektaş ve ark., 2023). Türkiye florasında 70'in üzerinde türle temsil edilen bu taksonun birçoğu endemik olup, geniş morfolojik varyasyonları ve

ekolojik uyum yetenekleri ile dikkat çekmektedir (Bektaş ve ark., 2023; Aliyazıcıoğlu ve ark., 2024). Türkiye coğrafyası, bu cinsin dünyadaki önemli gen merkezlerinden biri olarak kabul edilmekte ve çok sayıda endemik takson barındırmaktadır. Cinsin morfolojik açıdan sergilediği bu yüksek varyasyon, taksonomistlerin tür sınırlarını belirlemesinde zaman zaman zorluklara yol açmaktadır. Bu nedenle, klasik morfolojik karakterlerin yanı sıra biyokimyasal ve kemotaksonomik belirteçlerin ortaya konması, taksonomik ilişkilerin daha sağlam bir zemine oturtulması için büyük önem taşımaktadır.

Etnobotanik açıdan özellikle Doğu Karadeniz, İç Anadolu ve Doğu Anadolu bölgelerinde bazı *Ornithogalum* türlerinin toprak üstü kısımları (yapraklar, genç sürgünler) ve soğanları geleneksel halk hekimliğinde tedavi amaçlı ve yabani besin olarak yaygın biçimde tüketilmektedir (Özer ve ark., 2001; Ejder ve ark., 2024). Halk arasında genel olarak 'Akyıldız' veya 'Sakarca' olarak bilinen bu bitkilerin geleneksel halk tıbbındaki uygulamaları incelendiğinde, bu bitkilerin gastrointestinal rahatsızlıklar, enflamasyon, solunum yolu tıkanıklıkları, yara iyileşmesi ve cilt hastalıklarının tedavisinde kullanımı köklü bir geçmişe sahiptir (Plančić ve ark., 2015; Sharafi-Badr ve ark., 2022; Zengin v ark., 2015). Bazı yörelerde bitkinin toprak altı soğanları ezilerek ya da közlenerek apse ve çıbanların olgunlaştırılmasında haricen lapa olarak kullanılmaktadır. Taze ve genç sürgünleri ise haşlanıp kavrularak yöresel bir lezzet olarak tüketilmektedir. Bu kullanım çeşitliliği, bitkinin sadece gıda değerini değil, aynı zamanda barındırdığı biyoaktif fitokimyasalların farmasötik potansiyelini de ortaya koymaktadır.

Son yıllarda yapılan fitokimyasal çalışmalar, *Ornithogalum* türlerinin saponinler, steroidal glikozitler, homoyzoflavonoidler, alkaloitler ve zengin fenolik bileşikler gibi oldukça güçlü biyoaktif ikincil metabolitler içerdiğini kanıtlamıştır (Renda ve ark., 2019; Taşkın ve ark., 2021). Bu biyoaktif bileşiklerin varlığı, bitkiye güçlü antioksidan, antimikrobiyal, antifungal, anti-enflamatuar ve özellikle sitotoksik/antitümöral özellikler kazandırmaktadır (Iguchi ve ark., 2017; Zhan ve ark., 2021). Nitekim, literatürde yer alan moleküler çalışmalarda, bu cinsten izole edilen bazı spesifik steroidal glikozitlerin (örneğin OSW-1 bileşiği), çeşitli kanser hücre hatları üzerinde çok düşük konsantrasyonlarda bile güçlü sitotoksik etki gösterdiği bildirilmiştir (Zhan ve ark., 2021). Bu durum, *Ornithogalum* türlerini modern onkolojik araştırmalarda potansiyel ilaç etken madde kaynakları haline getirmektedir.

Bitkilerin sekonder metabolitlerinin yanı sıra primer lipit metabolizması ürünleri olan yağ asitleri de bitki sistematiğinde ve ekolojik adaptasyon süreçlerinde hayati roller üstlenmektedir. Ancak *Ornithogalum* türlerin yağ asidi profilleri ve bunların kemotaksonomik ilişkileri üzerindeki çalışmalar oldukça sınırlıdır. Yağ asitleri, bitki hücre zarlarının akışkanlığını kontrol ederek kuraklık, donma ve yüksek sıcaklık gibi çevre streslerine karşı adaptasyonu kolaylaştırır (Demir Perçin ve ark., 2026a; Demir Perçin ve ark., 2026b). Ayrıca, bitki taksonomisinde morfolojik karakterlerin yetersiz kaldığı durumlarda, yağ asitlerinin niteliksel ve niceliksel dağılımları kimyasal taksonomi (kemotaksonomi) açısından son derece değerli kanıtlar sunar. Çoğu araştırma ikincil metabolitlere (fenolikler, saponinler) odaklanırken, birincil metabolitlerin ve özellikle hücresel membranların temel taşı olan lipit bileşenlerinin taksonomik değeri göz ardı edilmiştir. Lipitler, bitkilerin hem taksonomik karakterizasyonunda hem de çevresel koşullarla etkileşiminde anahtar rol oynamaktadır. Bu çalışmada, ülkemizin biyoçeşitliliğine katkı sunmak amacıyla Türkiye'nin farklı illerinden (Elazığ, Bingöl, Malatya) toplanan endemik ve yaygın üç *Ornithogalum* türünün (*Ornithogalum narbonense*, *Ornithogalum yesilyurtense* ve *Ornithogalum yildirimlii*) soğan ve toprak üstü kısımlarının yağ asidi profilleri belirlenerek, bu profillerin biyokimyasal çeşitlilik ve kemotaksonomik açıdan önemi karşılaştırmalı olarak ele alınmıştır.

1.1 Kuramsal Çerçeve

Bitkilerde lipit metabolizması ve yağ asidi kompozisyonu, yalnızca hücresel membranların yapısal bütünlüğünü ve akışkanlığını korumak için değil, aynı zamanda enerji depolama ve çevresel stres koşullarına (kuraklık, tuzluluk, don ve sıcaklık dalgalanmaları vb.) adaptasyon süreçlerinde de son derece kritik bir rol üstlenmektedir. Bitki hücre zarlarının dinamik akışkanlığı, membranı oluşturan fosfolipitlerdeki doymamış yağ asitlerinin (özellikle mono-doymamış oleik asit ile poli-doymamış linoleik ve linolenik asitler) doymuş yağ asitlerine (başta palmitik ve stearik asitler olmak üzere) olan bağıl oranına doğrudan bağlıdır (Simopoulos, 1999). Membran lipidlerindeki bu doymuş/doymamışlık dengesi, hücrenin dış ortamdaki fiziksel değişimlere karşı verdiği fizyolojik tepkilerin temelini oluşturmaktadır.

Doymuş yağ asitlerinin yüksek oranlarda birikmesi, özellikle bitkinin toprak altı depolama organlarında (soğanlar) dormansi (uyku) döneminde hücresel membranların termal stabilitesini ve fiziksel direncini korurken; buna karşılık doymamış yağ asitlerinin baskınlığı, fotosentetik olarak aktif olan dokularda (yapraklar ve toprak üstü sürgünler) dinamik membran akışkanlığını, kloroplast bütünlüğünü ve membran üzerindeki sinyal iletim yollarını destekler (Simopoulos, 1999). Çevresel sıcaklık azaldığında, bitkiler membranlarının katılaşmasını (donmasını) önlemek için desatürasyon mekanizmalarını aktive ederek doymamış yağ asitlerini artırırlar. Sıcaklık arttığında ise, membranın aşırı akışkan hale gelip sızdırmasını önlemek için doymuş yağ asidi sentezi teşvik edilir.

Kemotaksonomi, bitki sistematiğinde morfolojik karakterlerin yetersiz kaldığı, fenotipik plastisitenin teşhisi zorlaştırdığı ya da yakın akraba taksonların kesin olarak ayırt edilmesi gerektiği durumlarda biyoaktif ikincil metabolitlerin ve lipit profillerinin kimyasal belirteç (marker) olarak kullanılması yöntemidir (Renda, 2024; Aytar ve ark., 2024). Yağ asitlerinin zincir uzunlukları, doymamışlık dereceleri ve izomerik dağılımları genetik olarak kontrol edilen enzimatik yolakların bir sonucu olduğundan, türe özgü kararlı yapılar sergilerler. *Ornithogalum* cinsinde türe özgü ve organa özgü olarak sergilenen yağ asidi dağılımları, taksonomik sınırların netleştirilmesinde ve kemotipleştirme çalışmalarında oldukça güçlü ve güvenilir bir taksonomik araç sunmaktadır.

2. MATERYAL VE METOT

2.1 Bitki Materyali ve Ekstraksiyon: *O. narbonense* örnekleri Nisan 2020'de Elazığ ili Obuz köyünün doğu kısımlarından ve tarihi Harput bölgesinin kuzey yamaçlarından (1200-1300 m rakım) toplanmıştır. Endemik *O. yesilyurtense* örnekleri Malatya- Yeşilyurt yakınlarındaki kayalık habitattan (1500-1700 m rakım) (Demir Perçin ve ark., 2026a), *O. yildirimlii* ise Elazığ ili Keban barajı çevresinden temin edilmiştir (Yıldırımlı ve Kılıç, 2017; Demir Perçin ve ark., 2026b). Bitkiler soğan ve toprak üstü (yaprak/gövde) olarak ayrılmış, gölgede kurutulup toz haline getirilmiştir. 20 g kurutulmuş bitki tozu, 100 mL metanol ile 48 saat oda sıcaklığında masere edilmiştir. Süzülen ekstraktlar döner buharlaştırıcıda konsantre edilmiş ve liyofilize edilerek kuru toz ekstraktlar elde edilmiştir (Demir Perçin ve ark., 2026a; Demir Perçin ve ark., 2026b; Demirpolat vd.; Tekeli ve Bezgin, 2025).

2.2 Yağ Asidi Analizleri: Bitki örneklerinin yağ asidi profillerinin belirlenmesi amacıyla gaz kromatografisi (GC) yöntemi kullanılmıştır. Kromatografik analizler, Shimadzu Nexis GC-2030 gaz kromatografisi cihazına bağlı alev iyonizasyon dedektörü (FID) ve Teknokroma TR-CN100 kapiler kolon (100 m × 0,25 mm iç çap, 0,20 µm film kalınlığı) kullanılarak gerçekleştirilmiştir. Kromatografik ayırımda fırın sıcaklığı başlangıçta 100 °C'ye ayarlanmış ve bu sıcaklıkta 4 dakika bekletilmiştir. Ardından sıcaklık 4 °C/dakika hızla 200 °C'ye yükseltilmiş, sonrasında 3 °C/dakika hızla 230 °C'ye çıkarılmış ve bu sıcaklıkta 15 dakika tutulmuştur. Böylece toplam analiz süresi 55 dakika olarak gerçekleştirilmiştir. Örneklerin enjeksiyonu 1 µL hacminde ve 20:1 split oranında yapılmış, enjektör sıcaklığı 240 °C olarak ayarlanmıştır. Taşıyıcı gaz olarak helyum (He) kullanılmış ve doğrusal akış hızı 18,10 cm/s olacak şekilde çalışılmıştır. Purge akış hızı 3,0 mL/dakika olarak belirlenmiştir. Yağ asitlerinin tespiti için FID sıcaklığı 240 °C olarak ayarlanmıştır. Dedektörde makeup gazı olarak helyum kullanılmış ve akış hızı 30 mL/dakika olarak belirlenmiştir. Dedektörün hidrojen ve hava akış hızları sırasıyla 40 ve 400 mL/dakika olarak ayarlanmıştır. Elde edilen kromatogramlar üzerinden örneklerin yağ asidi bileşimleri değerlendirilmiştir. (Demir Perçin ve ark., 2026a; Demir Perçin ve ark., 2026b).

3. BULGULAR VE TARTIŞMA

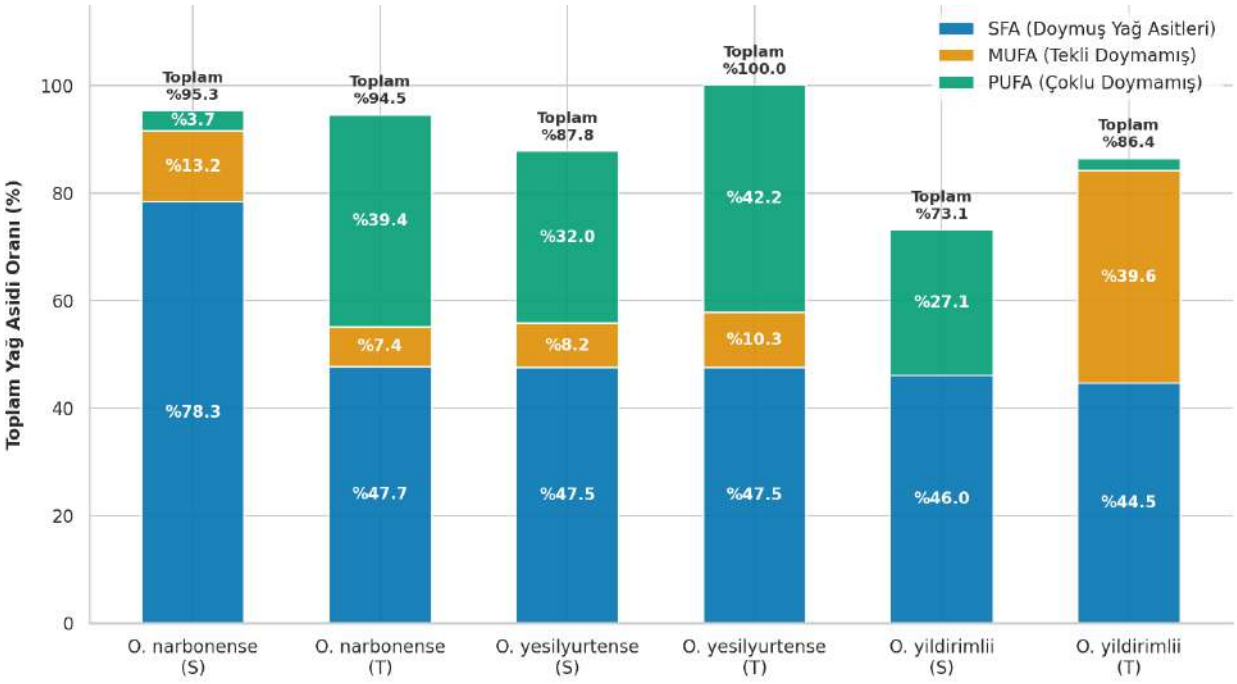
Bitki türleri üzerinde yapılan yağ asidi analizleri sonucunda, incelenen üç *Ornithogalum* türünde de organa özgü lipit metabolizması ve türler arası kimyasal farklılıklar saptanmıştır. Analiz edilen bitki kısımlarına tespit edilen başlıca yağ asitlerine ait veriler Tablo 1'de olarak sunulmuştur.

Tablo 1: *Ornithogalum* türlerinin yağ asidi analiz sonuçları (%100)

Yağ Asitleri (%)	*O. narbonense* (S)	*O. narbonense* (T)	*O. yesilyurtense* (S)	*O. yesilyurtense* (T)	*O. yildirimlii* (S)	*O. yildirimlii* (T)

Bütirik Asit (C4:0)	**2,13**	**0,38**	**1,51**	**2,66**	**1,77**	**0,66**
Kaproik Asit (C6:0)	**1,54**	**0,63**	**1,30**	**nd**	**1,26**	**1,07**
Myristik Asit (C14:0)	**2,01**	**5,31**	**1,77**	**14,79**	**1,66**	**4,33**
Pentadekanoik Asit (C15:0)	**7,76**	**4,70**	**7,44**	**nd**	14,04	3,10
Palmitik Asit (C16:0)	**48,82**	**24,54**	**25,72**	**24,15**	**18,08**	**26,07**
Stearik Asit (C18:0)	**10,71**	**12,15**	**4,58**	**5,87**	4,19	6,07
Oleik Asit (C18:1n9c)	**13,18**	**7,38**	**8,22**	**10,31**	nd	39,56
Linoleik Asit (C18:2n6c)	**3,73**	**11,07**	**28,15**	**11,82**	27,15	nd
Linolenik Asit (C18:3n3)*	**nd**	**19,24**	**2,28**	**15,17**	nd	nd
Gama-Linolenik Asit (C18:3n6)	**nd**	**9,08**	**1,58**	**14,09**	**nd**	**2,27**
Araşidik Asit (C20:0)	**1,61**	**nd**	**2,30**	**nd**	**1,65**	**0,91**
Trikosanoik Asit (C23:0)	**3,76**	**nd**	**2,91**	**nd**	**3,33**	**2.33**
DHA (C22:6n3)	**nd**	**nd**	**nd**	**1,16**	**nd**	**nd**

Tablo 1. Ornithogalum türlerinin soğan (S) ve toprak üstü (T) kısımlarında başlıca yağ asidi bileşenleri (%); (nd: tespit edilemedi / limitlerin altında).



Şekil 1. Türlere göre yağ aside oranlarının karşılaştırılması

Tablo 1 ve Şekil 1'den elde edilen bulgularda, her üç *Ornithogalum* türünün soğan ve toprak üstü kısımlarında farklı lipid metabolizmasına sahip olduğu görülmektedir. *O. narbonense* soğanlarında palmitik asit (%48.82) baskın doymuş yağ asidi (SFA) olarak belirlenmiştir. Bu durumun, soğan dokularında membran stabilitesinin korunmasına katkı sağlayabileceği düşünülmektedir. Buna karşılık aynı türün toprak üstü kısımlarında çoklu doymamış yağ asitlerinin daha yüksek oranlarda bulunması, fotosentetik dokularda membran akışkanlığının sürdürülmesi ile ilişkili olabilir. Bu bulgu literatürde bitki membran lipidleri için bildirilen genel eğilimlerle uyumludur. Bitkinin toprak üstü kısımlarında çoklu doymamış yağ asitleri (PUFA) olan α-linolenik asit (%19.24) ve linoleik asit (%11.07) oranlarıyla

ön plana çıkmaktadır (Şekil 1.). Bu durum, yapraklardaki fotosentez organ membranlarının yüksek akışkanlık ve dinamizm ihtiyacı ile mükemmel bir fizyolojik uyum sergilemektedir (Simopoulos, 1999).

Buna karşın, *O. yesilyurtense* soğanlarında poli-doymamış linoleik asit (%28.15) baskın yağ asidi olarak saptanmıştır. Bu türün soğanlarındaki doymamışlık derecesinin *O. narbonense*'ye göre daha yüksek olması, iki tür arasında soğan düzeyinde çok net bir metabolik farklılığa işaret etmektedir. *O. yesilyurtense*'nin toprak üstü kısımlarında ise palmitik asit (%24.15), linolenik asit (%15.17), linoleik asit (%11.82) ve oleik asit (%10.31) nispeten dengeli bir dağılım göstermektedir (Tablo 1). Bu dengeli profil, türün farklı ekolojik koşullarda hücresel dengesini korumasına yardımcı olan esnek bir lipit sentez yoluna sahip olduğunu düşündürmektedir.

Çalışmada gözlemlenen diğer bir bulgu ise, *O. yildirimlii* türünde saptanan yağ asitleridir. *O. yildirimlii*'nin toprak üstü kısımlarında yüksek oranda mono-doymamış oleik asit (%39.56) saptanırken, soğanlarında ise çok nadir görülen bir doymuş yağ asidi olan pentadekanoik asit (%14.05) tespit edilmiştir. Pentadekanoik asit (C15:0), tek sayıda karbon atomu içeren doymuş bir yağ asidi olup, bitkisel lipitlerde genellikle sadece eser miktarlarda bulunur veya hiç bulunmaz. Bu yağ asidinin *O. yildirimlii* soğanlarında %14.05 gibi yüksek bir oranda birikmesi, bu takson için, ayırt edici ve güvenilir bir kemotaksonomik belirteç (marker) sunmaktadır. Ayrıca *O. yildirimlii* soğanlarında stearik, oleik ve linolenik asitlerin tespit edilememesi (nd), buna karşılık toprak üstünde oleik asidin (%39.56) yüksek oranda bulunması, bu endemik taksonun kendine has, oldukça spesifik ve dar tanımlı bir lipit metabolizmasına sahip olduğunu biyokimyasal olarak ortaya koymaktadır.

Kemotaksonomik açıdan değerlendirildiğinde, bu üç türün yağ asitleri kompozisyonları önemli ayırıcı karakterler sunmaktadır:

• ***O. yildirimlii*** **Taksonu**: Bu türün toprak üstü kısımlarında saptanan %39,56 oranındaki olağanüstü yüksek cis-oleik asit düzeyi, onu diğer iki türden ayırır ve literatürdeki *O. nutans* (%35-40) profili ile yakın akrabalık ilişkisine işaret eder (Atay ve ark., 2024). Ayrıca soğanlarında %14,05 gibi yüksek bir oranda saptanan nadir pentadekanoik asit (C15:0), bu tür için imza niteliğinde bir kemotaksonomik markerdir (Demir Perçin ve ark., 2026).

• ***O. narbonense*** **Taksonu**: Soğan kısımlarında %48,82 gibi çok yüksek bir palmitik asit (C16:0) birikimi ile karakterizedir. Diğer türlere kıyasla soğanlarındaki doymamış yağ asidi oranı (%20,13) oldukça düşüktür. Toprak üstü kısımlarında ise linolenik asit izomerleri toplamı (%28,32) yüksek bir doymamışlık derecesi oluşturmaktadır.

• ***O. yesilyurtense Taksonu:*** Soğanlarında cis-linoleik asit (C18:2n6c) %28,15 oranıyla en baskın bileşendir. Bu yüksek linoleik asit seviyesi, literatürde rapor edilen *O. umbellatum* (%15-20) ve *O. sigmoideum* (%18-22) soğanlarındaki değerleri belirgin şekilde aşarak türler arası spesifik lipid metabolizmasını doğrulamaktadır (Aydin, 2020; Yalçın ve ark., 2020). O. yesilyurtense'nin toprak üstü kısımlarında düşük oranda (%1.16) DHA (C22:6n3) tespit edilmiştir. DHA kara bitkilerinde yaygın olarak rapor edilen bir yağ asidi olmadığından, bu sonucun ileri analiz yöntemleri (GC-MS ve uygun referans standartlar) ile doğrulanması gerekmektedir. Bu nedenle mevcut çalışma kapsamında söz konusu bileşen potansiyel bir bulgu olarak değerlendirilmiştir. Bu karakteristik kimyasal profiller, morfolojik benzerlikleri nedeniyle teşhisinde zorluk yaşanabilen bu üç yakın akraba *Ornithogalum* taksonunun kimyasal sistematik (kemotaksonomi) kurallarına göre moleküler düzeyde kolayca ayrılmasını sağlamaktadır. Yağ asitlerinin organa ve türe özgü bu dağılımları, cins içindeki taksonomik farklılıkların belirlenmesinde biyokimyasal bir belirteç olarak değerlendirilebilir.

4. SONUÇ

Bu araştırma, ülkemizin endemik ve yaygın florasında yer alan *Ornithogalum* türlerinde lipit kompozisyonunun taksonomik sınırları belirleme ve ekolojik adaptasyon mekanizmalarını anlama konusundaki değerini açıkça ortaya koymaktadır. *O. narbonense*, *O. yesilyurtense* ve *O. yildirimlii* türlerinin hem toprak altı soğan hem de toprak üstü kısımlarının yağ asidi profilleri karşılaştırıldığında, her bir taksonun kendine has, genetik olarak belirlenmiş çok spesifik birer 'metabolik parmak izine' sahip olduğu kanıtlanmıştır. Fizyolojik adaptasyon açısından; soğanlarda doymuş yağ asitlerinin (özellikle C16:0) yoğunluğu toprak altı dokularda stabilitesini sağlarken, yaprak ve gövde gibi toprak üstü

kısımlarda çoklu doymamış yağ asitlerinin (C18:2, C18:3) yüksek oranları bitkinin aktif büyüme dönemindeki canlılığını ve fizyolojik performansını korumasına yardımcı olmaktadır.

Kemotaksonomik açıdan değerlendirildiğinde; *O. yildirimlii*'de saptanan yüksek pentadekanoik asit (%14.05) ve cis-oleik asit (%39.56) baskınlığı, *O. yesilyurtense* soğanlarındaki yüksek linoleik asit (%28.15) birikimi ve *O. narbonense* soğanlarındaki palmitik asit (%48.82) varlığı yakın akraba türlerin ayırt edilmesine olanak sunmaktadır. Bu bulgular, morfolojik karakterlerin çevresel faktörlerle gölgelendiği durumlarda, lipit analizlerinin güvenilir birer taksonomik araç olarak sistematiğe entegre edilebileceğini göstermektedir.

Ayrıca, bu çalışmada elde edilen yağ asidi profilleri, söz konusu bitkilerin farmasötik, kozmetik ve fonksiyonel gıda endüstrisinde yeni biyoaktif ham madde kaynakları olarak değerlendirilme potansiyelini de desteklemektedir. Özellikle yüksek oranda doymamış yağ asitleri içeren ekstreler, anti-enflamatuar ve antioksidan özellikleriyle yeni formülasyonların geliştirilmesinde kullanılabilir. Gelecekte, farklı coğrafi lokasyonlardan ve farklı vejetasyon dönemlerinden toplanacak örneklerle yapılacak daha geniş kapsamlı çalışmalar, bu kimyasal varyasyonların genetik ve çevresel boyutlarını daha da netleştirecek ve bitkilerin ekonomik değerini artıracaktır.

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MERCAN RESİFLERİNDE AĞARMA TESPİTİ İÇİN DERİN ÖĞRENME MODELLERİNİN KARŞILAŞTIRILMASI VE COREFNET MİMARİSİ

COMPARISON OF DEEP LEARNING MODELS FOR CORAL BLEACHING DETECTION AND THE COREFNET ARCHITECTURE

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ÖZET

Mercan resifleri, deniz biyoçeşitliliğinin devamlılığı açısından önemlidir. Ancak günümüzde iklim krizi, okyanuslardaki asitlenme ve insan kaynaklı olumsuz yaklaşımlar bir tehdite dönüşmüştür. Resiflerin sağlığını kaybettiğini gösteren en net kanıtlardan biri olan mercan ağarması (bleaching), artık dünya çapında yakından takip edilmesi gereken çevresel bir kriz haline gelmiştir. Eski nesil manuel izleme teknikleri vakit ve bütçe açısından yetersizdir. Bu nedenle süreci otomatikleştiren bilgisayar destekli sistemlere ihtiyaç duyulmaktadır. Bu çalışma kapsamında, resiflerdeki sağlık durumunu otomatik şekilde tespit edebilmek adına derin öğrenme yaklaşımları kullanılmıştır. Kaggle'dan açık erişimle temin edilen toplam 8.304 görüntünün yer aldığı Corals Classification veri seti ile çalışılmıştır. Veri kümesinde 7384 görüntü eğitim için 923 görüntü ise test için kullanılmıştır. MATLAB ortamında AlexNet, VGG-16, VGG-19, SqueezeNet, ResNet-18, ResNet-50 ve ShuffleNet ve GoogLeNet ön-eğitimli sekiz evrişimli sinir ağı model ile eğitim ve test süreci gerçekleşmiştir. Bunlara ek olarak, mercan resifi görüntülerine özgü çok ölçekli paralel evrişim yolları ve çift havuzlama GAP+GMP füzyon mekanizmasına sahip, yaklaşık 6,5 milyon parametreli özgün CorefNet mimarisi sıfırdan tasarlanarak eğitilmiştir. Tüm modeller ağarmış ve sağlıklı olmak üzere iki farklı sınıfta çalıştırılmıştır. Test sonuçlarına baktığımızda en yüksek doğruluk oranına %96,81 ile ResNet-50 ulaşırken, VGG-19 %96,63 ve VGG-16 %96,57 onu yakından takip etmiştir. Hafif mimarilerden GoogLeNet %92,53, ShuffleNet ve ResNet-18 de %94 seviyesinde yüksek doğruluklar sergilemiştir. Sıfırdan eğitilen CorefNet modeli ise herhangi bir önceden eğitilmiş ağırlık kullanmaksızın %91,66 doğruluk elde ederek AlexNet %85,19 ve SqueezeNet %84,59 modellerinden daha iyi performans sergilemiştir. Bu sonuçlar, özgün olarak tasarlanmış orta ölçekli bir mimarinin, hazır modellerle rekabet edebilir bir seviyeye çıkabileceğini göstermektedir.

Anahtar Kelimeler: Mercan resifleri, mercan ağarması, derin öğrenme, transfer öğrenme, görüntü sınıflandırma.

ABSTRACT

Coral reefs are crucial for the sustainability of marine biodiversity. However, climate change, ocean acidification, and negative human-induced practices have become a threat. Coral bleaching, one of the clearest pieces of evidence indicating the loss of reef health, has become a global environmental crisis requiring close monitoring. Older manual monitoring techniques are insufficient in terms of time and budget. Therefore, computer-aided systems that automate the process are needed. In this study, deep learning approaches were used to automatically detect the health status of reefs. The Corals Classification dataset, containing a total of 8,304 images obtained from open access on Kaggle, was used. 7,384 images were used for training and 923 images for testing. Training and testing were carried out in MATLAB using eight pre-trained convolutional neural network models: AlexNet, VGG-16,

VGG-19, SqueezeNet, ResNet-18, ResNet-50, ShuffleNet, and GoogLeNet. In addition, a unique CorefNet architecture with approximately 6.5 million parameters, featuring multi-scale parallel convolution paths specific to coral reef imagery and a dual-pooling GAP+GMP fusion mechanism, was designed and trained from scratch. All models were run in two different classes: bleached and healthy. Looking at the test results, ResNet-50 achieved the highest accuracy rate at 96.81%, followed closely by VGG-19 at 96.63% and VGG-16 at 96.57%. Among the lightweight architectures, GoogLeNet showed high accuracies at 92.53%, while ShuffleNet and ResNet-18 also achieved high accuracies at 94%. The CorefNet model trained from scratch achieved an accuracy of 91.66% without using any pre-trained weights, outperforming the AlexNet 85.19% and SqueezeNet 84.59% models. These results demonstrate that a uniquely designed medium-scale architecture can reach a level that is competitive with readily available models.

Keywords: Coral reefs, coral bleaching, deep learning, transfer learning, image classification.

1. Giriş

Mercan resiflerinin okyanus tabanında kapladığı alan %0.1'den azdır. Ancak sayısal olarak deniz canlılarının önemli bir kısmını oluşturmaktadır. Bu canlılar genellikle tropikal sularda bulunmaktadır. Bu canlılar insan yaşamına fayda sağlayabilecek özelliklere sahiptir. Turizm, balıkçılık, ilaç sanayisi gibi alanlarda kullanılmaktadır (Hughes ve ark., 2003; Burke ve ark., 2011; Welle ve ark., 2017). Bu canlılar küresel ısınmanın etkisi, denizdeki asit oranındaki artış, kontrolsüz avlanma, insan kaynaklı atıklar ve kıyı şeridindeki betonlaşma nedeniyle yaşamsal tehlike altındadırlar (Welle ve ark., 2017; Carlson ve ark., 2019).

Mercan poliplerinin bünyesinde simbiyotik yaşayan ve onlara hem enerji hem de renk veren zooksantel adlı alglerin (*Symbiodinium spp*.), çevresel stres anında dışarı atılması sürecine "mercan ağarması" denmektedir (Hoegh-Guldberg, 1999). Renkleri solup beyaza dönen mercanlar, temel besin kaynaklarından mahrum kaldıkları için bu duruma uzun süre maruz kalırlarsa tamamen ölmektedirler. 1980'lerde 25 ila 30 yılda bir rastlanan kitlesel ağarma vakalarının, 2016'lara gelindiğinde 6 yılda bir görülmeye başladığı ve sadece 2016'daki tek bir olayda Büyük Set Resifi'nin %91'inin zarar gördüğü saptanmıştır (Hughes ve ark., 2017; Welle ve ark., 2017). Karayipler'de yaşanan 2005 ağarmasını incelediğinde, yüksek sıcaklığın mercanlar üzerindeki tahribatının, insan kaynaklı diğer faktörlerden dört kat daha yıkıcı olduğunu gözlemlemiştir. Yakın tarihli bir başka araştırmada ise 2016 ve 2017 yıllarında yaşanan ısı şoklarının mercanların iyileşme hızını türe bağlı olarak değiştirdiği ve koruma planlarının buna göre güncellenmesi gerektiği vurgulanmıştır(Anderson-King ve ark., 2023).

Dolayısıyla resiflerin ne durumda olduğunu hızlıca ve geniş ölçekte haritalayabilecek yöntemlere acilen ihtiyaç duyulmaktadır. Su altı fotoğraf çekmek veya çeşitli fiziksel ölçümler yapmak son derece kesin veriler sağlasa da, bu klasik yöntemler hem çok masraflı hem de oldukça zaman alan bir süreçtir (Zamani ve Madduppa, 2011). Yapılan araştırmalar, uydudan alınan görüntülerle hesaplanan sağlık indekslerinin faydalı olduğunu ancak henüz tam bir standardın oturmadığını göstermektedir (Hafizt ve ark., 2023).

Son dönemin yükselen teknolojisi derin öğrenme, özellikle görüntü işlemeye odaklanan evrişimli sinir ağları (CNN) sayesinde bu alanda büyük fırsatlar sunmaktadır (Krizhevsky ve ark., 2012; Simonyan ve Zisserman, 2015; Doğan ve Türkoğlu, 2018, 2019). ImageNet gibi kütüphanelerde önceden eğitilmiş modeller, transfer öğrenme yöntemiyle çok daha kısıtlı veriye sahip deniz biyolojisi gibi niş alanlara kolayca adapte edilebilmektedir. Elmezain vd.(Elmezain ve ark., 2026) , nesne tespiti ve bölütleme mantığına dayanan Coral-CRCA adlı bir algoritmayla ağarmanın derecesini nesnel olarak saptamayı başarmıştır. Sorunun boyutu giderek büyüdüğünden; yüksek enlemlerdeki görece serin suların bile artık mercanlar için güvenli bir sığınak olmaktan çıktığı belirtilmektedir (Dalton ve Carroll, 2011). İnsan yerleşimine yakın bölgelerde resif örtüsünün hızla azaldığı (Smith ve ark., 2016) gerçeği göz önüne alındığında, bilgisayar tabanlı tespit araçları bir gereklilik haline gelmiştir.

Bu çalışmada sağlıklı ve ağarmış mercan görüntülerinin transfer öğrenme kullanılarak sekiz ön eğitimli AlexNet, VGG-16, VGG-19, SqueezeNet, ResNet-18, ResNet-50, ShuffleNet, GoogLeNet ve önerilen

CorefNet derin öğrenme modelleri ile sınıflandırması ve karşılaştırmalı olarak performansları incelenmiştir. MATLAB üzerinde yapılan analizlerle bu ağların başarısı, hatalı ölçümleri ve geri çağırma skorları detaylıca incelenmiş; derin veya yüzeysel yapıdaki algoritmaların resif analizindeki kapasiteleri karşılaştırılarak gelecekteki otonom sistemler için fikir verilmesi hedeflenmiştir.

Çalışmada, su altından elde edilen mercan resifi görüntüleri sağlıklı ve ağarmış olarak ikili sınıflandırmaya tabi tutulmuş ve 9 farklı derin öğrenme modeli aynı veri seti üzerinde karşılaştırılmıştır. Bunlardan 8 tanesi literatürde sıkça kullanılan ön eğitimli ağlardır: AlexNet, VGG-16, VGG-19, SqueezeNet, ResNet-18, ResNet-50 ShuffleNet ve GoogLeNet. Önerilen model ise mercan resifi görüntülerinin kendine has özelliklerine uygun olarak sıfırdan özgün CorefNet mimarisidir. Bu kapsamda çalışmanın katkıları şöyle özetlenebilir:

- Mercan resiflerinin sınıflandırması için AlexNet, SqueezeNet, VGG-16, VGG-19, ResNet-18, ResNet-50, ShuffleNet, GoogLeNet sekiz derin öğrenme mimarisi ön eğitimli olarak aynı veri seti ve aynı deneysel koşullar altında olarak karşılaştırılmıştır.

- Mercan resifi sınıflandırma problemine özgü, çok ölçekli paralel evrişim yolları (Omni-Vision blokları) ve çift havuzlama füzyonu (CorefFusion) içeren CorefNet mimarisi sıfırdan tasarlanmış ve performansı diğer modellerle karşılaştırılmıştır.

- Doğruluk, hassasiyet, geri çağırma ve F1-skoru gibi standart metriklerin yanı sıra parametre sayısı, model boyutu ve eğitim süresi de değerlendirme kriterlerine dahil edilerek yalnızca doğruluk odaklı değil, aynı zamanda hesaplama maliyeti odaklı bir analiz gerçekleştirilmiştir.

- Sıfırdan eğitilen CorefNet modelinden elde edilen sonuçlar ön eğitimli modellere alternatif bir seçenek olarak sunulmuştur.

- Elde edilen sonuçlar, gerçek zamanlı resif izleme sistemlerinin tasarımında model seçimi için somut bir referans çerçevesi sunmaktadır. Su altı robotları veya otonom araçlara entegre edilebilecek özgün modellerin pratik uygulanabileceği düşünülmektedir.

2. Literatür Taraması

Mercan resiflerinin sınıflandırılması için literatürde geleneksel makine öğrenmesi ve derin öğrenme mimarileri ile yapılmış çeşitli çalışmalar bulunmaktadır. Geleneksel görüntü işleme yöntemleriyle yapılan ilk çalışmalarda mercanların renk, doku ve yapısal özelliklerinin çıkarılması manuel olarak yapılmaktaydı (Shihavuddin ve ark., 2013). Son yıllarda bilgisayarlı görü alanındaki ilerlemelerle birlikte evrişimli sinir ağları kullanılarak özellik çıkarımı otomatikleştirilmiş ve çok daha yüksek başarılı sonuçlar elde edilmeye başlanmıştır (Krizhevsky ve ark., 2012).

Mevcut çalışmalar incelendiğinde, araştırmacıların veri kaynağı olarak su altı fotoğraflarını ve uydu görüntülerini kullandıkları görülmektedir. Su altı fotoğrafları mercan yüzeyindeki doku, pigmentasyon ve iskelet yapısı gibi detayları yüksek çözünürlükte sunduğundan doğrudan sınıflandırma için tercih edilmektedir. Uydu ve uzaktan algılama görüntüleri ise geniş alanların haritalanması ve sağlık indeksi hesaplanması için kullanılmaktadır (Hafizt ve ark., 2023; Chariyev ve ark., 2025). Yöntem bazında bakıldığında ise araştırmacıların destek vektör makineleri (SVM) ve rastgele ormanlar gibi klasik sınıflandırıcılarla başarılı sonuçlar elde ettiği görülmüştür. Sonraki çalışmalarda CNN tabanlı transfer öğrenme yaklaşımlarının kullanılmıştır (Beijbom ve ark., 2012; González-Rivero ve ark., 2016; Doğan ve ark., 2024). Ayrıca hesaplama maliyetini düşürmeyi hedefleyen hibrit mimariler, nesne tespiti ve bölütleme odaklı yaklaşımlar (Elmezain ve ark., 2026) ile Transformer tabanlı modeller de son dönemde literatürde yer bulmaya başlamıştır (Doğan, 2026). Literatürde öne çıkan bu farklı yaklaşımların kullandığı yöntemler, odaklandıkları veri tipleri, üzerinde çalıştıkları sınıf sayıları ve elde ettikleri doğruluk oranları Tablo 1'de verilmiştir.

Tablo 1. Mercan resifi sınıflandırması ve sağlık tespiti üzerine temsili çalışmaların özeti.

Çalışma	Yıl	Yöntem Model	Veri Tipi	Sınıf	Doğruluk (%)
Beijbom vd.(Beijbom ve ark., 2012)	2012	SVM + Özellik Çıkarımı	Su Altı Fotoğrafları (Moorea LTER)	9	~90,00
González-Rivero vd.(González-Rivero ve ark., 2016)	2016	CNN (Özel Mimari)	Su Altı Fotoğrafları (Catlin Seaview)	5	~89,00
King vd.(King ve ark., 2018)	2018	VGG-16 (Transfer Öğrenme)	Su Altı Fotoğrafları (BENTHOZ-2015)	5	~92,00
Gómez-Ríos vd.(Gómez-Ríos ve ark., 2019)	2019	ResNet-50 (Transfer Öğrenme)	Su Altı Fotoğrafları (Eilat, RSMAS)	8	~95,10
Chariyev vd.(Chariyev ve ark., 2025)	2025	Denetimli Sınıflandırma + CBS	Uydu Görüntüleri (Sentinel-2, Landsat 8)	3	~88,50
Elmezain vd.(Elmezain ve ark., 2026)	2026	YOLOv11 + SAM (Coral-CRCA)	Su Altı Fotoğrafları (Kızıldeniz)	4	~98,50

Tablo 1'deki çalışmalar değerlendirildiğinde, kullanılan veri kümesinin ve tercih edilen mimarinin doğruluk oranı üzerinde etki ettiği görülmektedir. Çalışmalarda elde edilen sonuçların %88 ile %98 arasında değiştiği görülmektedir. Erken dönem çalışmalar klasik özellik çıkarımı ve sığ CNN mimarileriyle yüksek doğruluk elde etse de düşük sınıf sayılı veri setleri üzerinde çalışmışlardır(Beijbom ve ark., 2012; González-Rivero ve ark., 2016). Başka bir çalışmada bentik habitatların ayrımında transfer öğrenmenin potansiyelini ortaya konmuştur (Anderson-King ve ark., 2023). Başka bir çalışmada nesne tespiti ve bölütleme odaklı hibrit bir yaklaşımla en yüksek doğruluğa ulaşmıştır (Elmezain ve ark., 2026). Ancak tüm bu çalışmalarda modellerin büyük çoğunluğu önceden eğitilmiş ağırlıklara dayanmakta olup, mercan resifi sınıflandırma problemine özgü sıfırdan tasarlanan mimari önerileri oldukça sınırlı kalmaktadır. Bu durum, mevcut literatürdeki bu kısıtlılıktan farklı olarak, hem ön eğitimli modelleri hem de probleme özgü sıfırdan tasarlanan CorefNet mimarisini aynı veri seti üzerinde karşılaştırmaktadır. Mercan sağlığı sınıflandırmasında hız ve doğruluk dengesi bakımından en uygun yaklaşımların belirlenmesini hedefleyen bu çalışmanın temel motivasyonunu oluşturmaktadır.

3. Materyal ve Metot

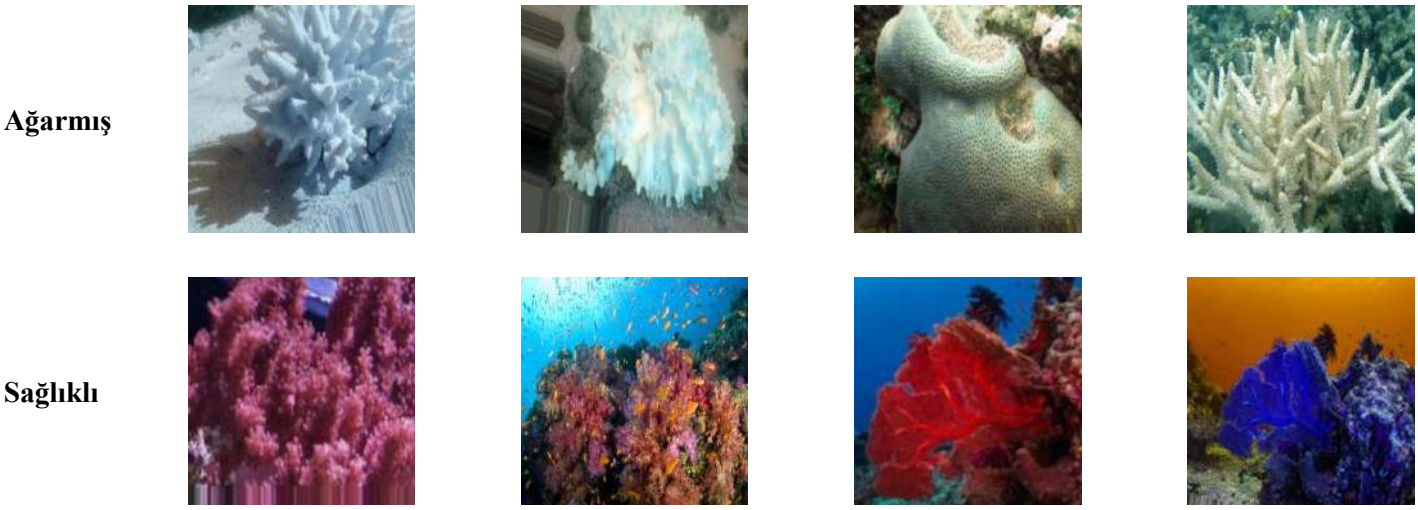
3.1 Veri Kümesi

Çalışmada, Kaggle platformu üzerinden erişilen "Bleached Corals and Healthy Corals Classification" veri seti kullanılmıştır (Dighe, 2023). Veri kümesi, okyanus ekosistemindeki mercanları sağlık durumlarına göre "Ağarmış Mercanlar" (Bleached) ve "Sağlıklı Mercanlar" (Healthy) olmak üzere iki sınıfa ayırmaktadır. Modellerin eğitimi ve test edilmesi amacıyla görüntüler ayrılmıştır. Veri kümesinde eğitim için 7.384, test için ise 923 olmak üzere toplam 8.307 görüntü bulunmaktadır. Sınıfların eğitim ve test veri kümelerindeki dağılımı Tablo 2'de detaylı olarak verilmiştir.

Tablo 2. Veri kümesinin eğitim, test sınıflarına göre dağılımı.

Sınıf	Eğitim	Test	Toplam
Ağarmış (Bleached)	3.880	485	4.365
Sağlıklı (Healthy)	3.504	438	3.942
Toplam	7.384	923	8.307

Veri kümesinde yer alan görüntü örnekleri Şekil 1'de sunulmuştur. Her bir modellerin girdi katmanları farklı boyutlar beklediğinden, görüntüler her model için ilgili boyuta ölçeklenmiş biçimde ön işlem uygulanmıştır.



Şekil 1. Veri kümesinden elde edilen örnek ağarmış ve sağlıklı mercan görüntüleri.

3.2 Ön Eğitimli Modeller ve Transfer Öğrenme Stratejisi

Transfer öğrenme, daha önce çok sınıflı bir veri kümesi ile eğitilmiş ve ağırlıkları bu veri kümesine göre bellirlenmiş modeli ifade etmektedir. MATLAB ortamı üzerinden yürütülen çalışmada sekiz adet ön eğitimli model ve bir adet sıfırdan tasarlanan özgün model olmak üzere toplam dokuz mimari ele alınmıştır. Ön eğitimli modellerin her birinde son tam bağlantılı katman silinip yerine "ağarmış veya sağlıklı" şeklinde iki seçenekli yeni bir karar düğümü eklenmiştir. Tüm modeller 35 tur boyunca, tek bir ekran kartı üzerinde eğitilmiştir.

3.3 AlexNet

Krizhevsky vd. (2012) tarafından geliştirilen ilk derin öğrenme mimarilerinden biridir. 5 evrişim katmanından oluşan ve yaklaşık 60 milyon parametre kullanan, toplam 25 katmanın yer aldığı temel bir mimaridir (Krizhevsky ve ark., 2012).

3.4 SqueezeNet

Iandola vd. (2016) tarafından, hafif olması için tasarlanan SqueezeNet, "Fire modülleri" adı verilen özel bloklar sayesinde parameter sayısı azaltılmıştır (Iandola ve ark., 2016). AlexNet'ten daha az bellek ihtiyacı olan ve donanım gereksinimi düşük cihazlarda kullanılmaya uygun bir mimaridir.

3.5 VGG-16

Simonyan ve Zisserman (2015) tarafından kurgulanan VGG-16, sistemin derinliğini artırarak performansın yükseltilmesi hedeflenmiştir (Simonyan ve Zisserman, 2015). 16 derinliğe sahip, 138 milyon parametresi olan ve donanım ihtiyacı yüksek olan ağır bir modeldir.

3.6 VGG-19

VGG ailesinden olan VGG-19, içindeki ekstra katmanlar sayesinde resimlerdeki daha ufak detayları yakalamaya odaklanır (Simonyan ve Zisserman, 2015). 19 derinliğe sahip, 144 milyon parameter içeren ve donanım gereksimini yüksek olan bir modeldir.

3.7 ResNet-18

He vd. (2016) tarafından geliştirilen ResNet ailesinin üyesi olan ResNet-18, 18 derinlik katmanlı yapısıyla atlama bağlantıları (residual connections) sayesinde derin ağlarda ortaya çıkan gradient kaybolma sorununa çözüm olarak sunulan bir derin öğrenme modelidir (He ve ark., 2016). Yaklaşık 11,7 milyon parametre barındırmaktadır.

3.8 ResNet-50

ResNet ailesinden olan ResNet-50, 50 derinlik katmanlı daha derin bir yapıya sahiptir. Bottleneck blokları sayesinde yaklaşık 25,6 milyon parametreyle hem hesaplama verimliliğini hem de öğrenme kapasitesini dengeler (He ve ark., 2016).

3.9 ShuffleNet

Mobil ve gömülü cihazlar için tasarlanan ShuffleNet, kanal karıştırma (channel shuffle) mekanizması sayesinde hesaplama maliyetini ciddi ölçüde düşüren hafif bir mimaridir (Zhang ve ark., 2018). Yaklaşık 1,4 milyon parametreye sahiptir.

3.10 GoogLeNet

GoogLeNet, 22 derinlik katmanlı bir mimariye sahip olup Inception modülleri sayesinde farklı boyutlardaki evrişim filtrelerini (1x1, 3x3, 5x5) paralel olarak kullanır. Model hem yerel hem de global özellikleri aynı anda çıkarabilmektedir (Szegedy ve ark., 2015). Hesaplama verimliliği yüksek olan bu model, çalışmada mercan resiflerindeki ağarma tespiti için önceden eğitilmiş ağırlıklarıyla transfer öğrenme sürecine dahil edilmiştir.

3.11 Önerilen Model CorefNet

Ön eğitimli sekiz model, tamamı eğitilmiş hazır modellerdir. ImageNet'ten aktarılan bilgi birikiminden faydalanmaktadırlar. Ancak bu çalışmada mercan resifi görüntülerinin kendine has renk ve doku özelliklerine uygun şekilde sıfırdan tasarlanan CorefNet isimli özgün bir mimari geliştirilmiştir.

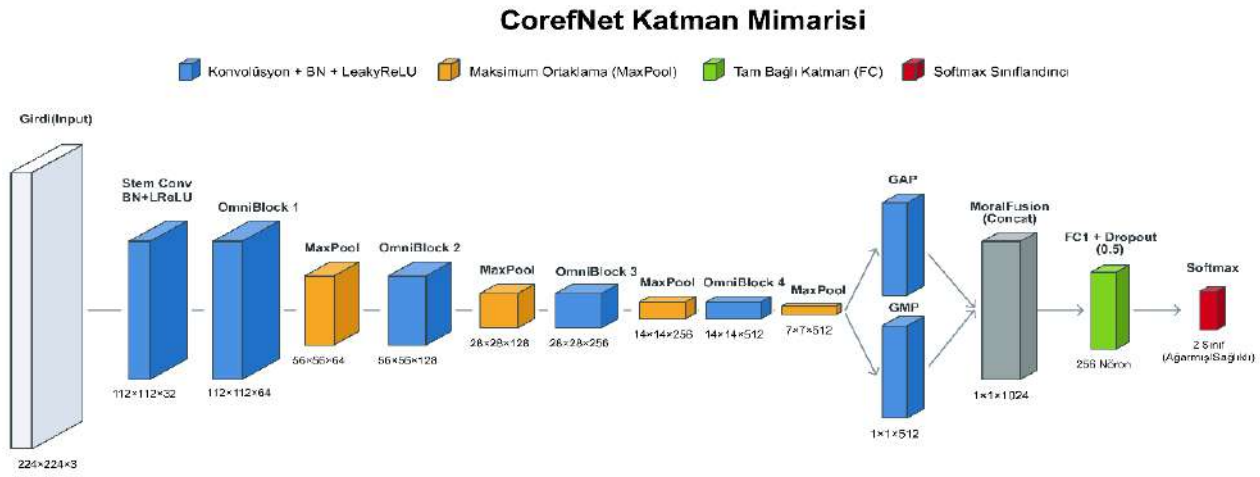
CorefNet'in omurgasını "Omni-Vision" adı verilen çok ölçekli paralel evrişim blokları oluşturmaktadır. Her blokta giriş verisi iki ayrı yola ayrılmaktadır. Birinci yolda 3×3 boyutlu filtreler ince doku detaylarını (mercan yüzeyindeki mukus tabakası, iskelet çizgileri, zooksantel pigment dağılımı gibi) tararken, ikinci yolda 5×5 boyutlu filtreler daha geniş bağlamsal bilgiyi (koloninin genel renk tonu, ağarma bölgesinin yayılım alanı gibi) yakalamaktadır. İki yolun çıktıları derinlik boyutunda birleştirilip bir refine evrişim katmanından geçmektedir. Böylece ince detaylar ile geniş bağlam arasındaki etkileşim öğrenilmiş olur. Her blokta ayrıca 1×1 boyutlu skip bağlantısı bulunmaktadır. Bu bağlantı, derin katmanlardaki gradient kaybolma sorununu önleyerek eğitimin kararlılığını artırmaktadır. Ağ boyunca kanal sayısı 32'den başlayarak kademeli olarak 64, 128, 256 ve 512'ye yükselmektedir.

Çıkış aşamasında ise "CorefFusion" adı verilen çift havuzlama mekanizması devreye girmektedir. Burada Global Average Pooling (GAP) ortalama özellik haritasını, Global Max Pooling (GMP) ise en baskın sinyalleri çıkarır; ikisinin birleştirilmesiyle 1.024 boyutlu bir özellik vektörü elde edilir. Bu vektör, sırasıyla %50 ve %25 oranında iki dropout katmanından geçirildikten sonra 256 nöronlu tam bağlantılı bir katmana ve ardından 2 sınıflı softmax çıkışına bağlanır. Aktivasyon fonksiyonu olarak standart ReLU yerine Leaky ReLU (α=0,1) tercih edilmiştir. Modelin katmansal yapısı ve parametre bilgileri tablo 3'te verilmiştir.

Tablo 3. CorefNet modelinin katman bazında parametre dağılımı.

Katman	Çıktı Boyutu	Parametre
Girdi	224×224×3	0
Omni-Vision Blok 1 (32 Kanal)	112×112×32	24.576
Omni-Vision Blok 2 (64 Kanal)	56×56×64	98.304
Omni-Vision Blok 3 (128 Kanal)	28×28×128	393.216
Omni-Vision Blok 4 (256 Kanal)	14×14×256	1.572.864
Refine Evrişim (512 Kanal)	7×7×512	4.194.304
CorefFusion (GAP + GMP)	1.024	0
Tam Bağlı (FC)	256	262.400
SoftMax	2	514
Toplam	—	6.546.178

Mimari Özellikleri: - Girdi boyutu: 224 × 224 × 3 piksel - Omni-Vision blokları: 4 blok (paralel 3×3 + 5×5 yolları, refine + skip bağlantısı) - Kanal akışı: 32 → 64 → 128 → 256 → 512 - Füzyon mekanizması: CorefFusion (GAP + GMP → 1.024 boyutlu vektör) - Düzenlileştirme: Dropout (%50 + %25) ve L2 regularizasyon (1e-4) - Aktivasyon fonksiyonu: Leaky ReLU (α=0,1) - Optimizasyon algoritması: Adam - Toplam parametre sayısı: ~6,5 milyon. Model görünümü şekil 2'de yer almaktadır.

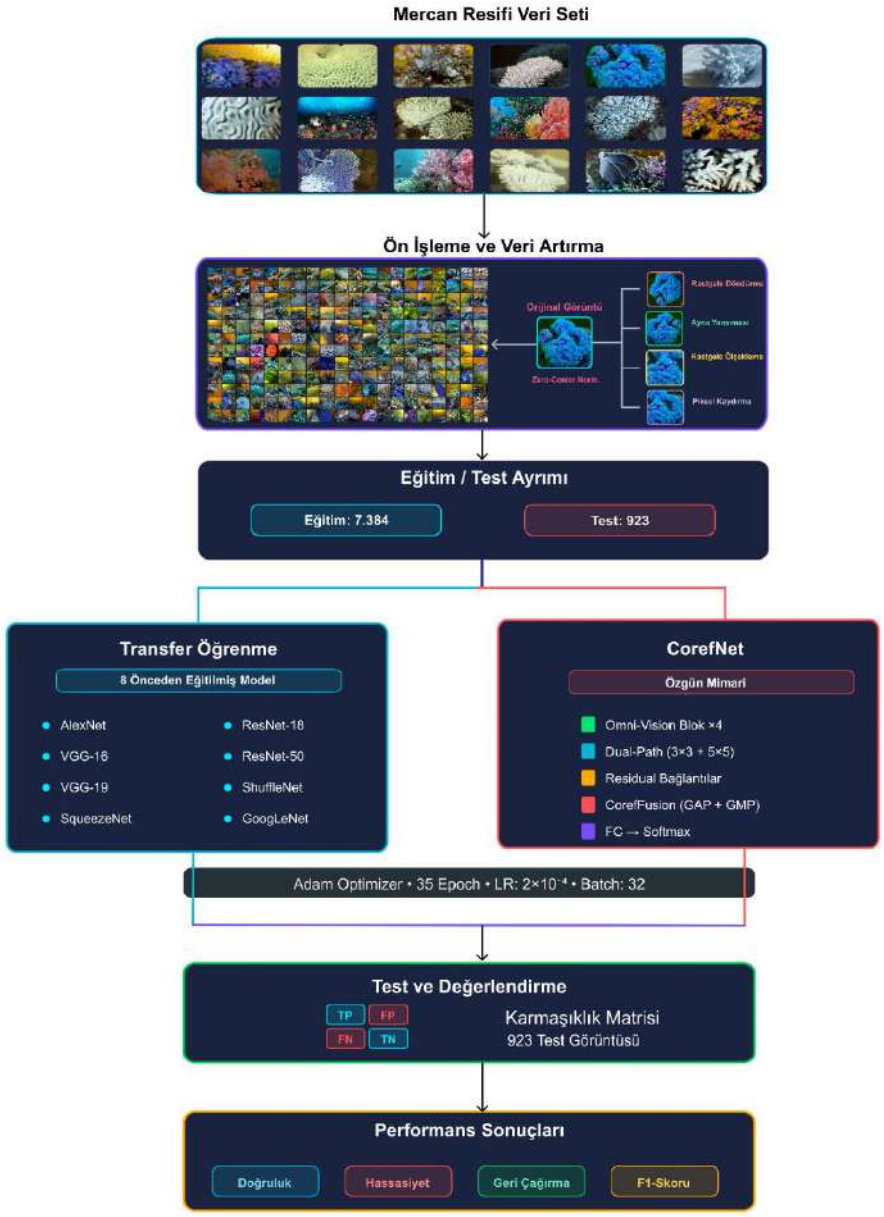


Şekil 2. CorefNet Modelinin katman mimarisi.

3.12 Deneysel Çalışma

Önerilen özgün CorefNet modeli, MATLAB Derin Öğrenme Araç Kutusu kullanılarak sıfırdan eğitilmiştir. Modelin eğitim sürecinde optimizasyon yöntemi olarak Adam (Adaptive Moment Estimation) algoritması tercih edilmiştir. Ağırlıkların verimli bir şekilde güncellenebilmesi için başlangıç öğrenme oranı 0,0002 ve toplam epoch sayısı 35 olarak belirlenmiştir. Eğitim sırasında mini-batch boyutu 32 olarak ayarlanmış olup, modelin genelleme yeteneğini artırmak amacıyla parçalı

öğrenme oranı düşürme stratejisi (piecewise) uygulanmıştır. Öğrenme oranı her 12 epoch'ta bir 0,5 katsayısıyla düşürülmüş ve L2 düzenlileştirme katsayısı 10^{-4} olarak belirlenmiştir. Veri hazırlama adımından performans değerlendirmesine kadar uzanan tüm deneysel çalışmanın akış diyagramı Şekil 3'de verilmiştir.



Şekil 3. Deneysel çalışmanın akış diyagramı.

3.13 Değerlendirme Metrikleri

Hangi yapay zekanın daha iyi olduğunu belirlemek için sadece "kaç tanesini doğru bildiğine" bakılmaz. Aşağıdaki hesaplamalar kullanılarak performansları ölçülmüştür:

Doğruluk (Accuracy): Toplam doğru tahmin oranını gösterir(Sokolova ve Lapalme, 2009).

$$\text{Accuracy} = \frac{\text{TP}+\text{TN}}{\text{TP}+\text{TN}+\text{FP}+\text{FN}} \qquad \text{Denklem 1}$$

Kesinlik (Precision): Pozitif tahminlerin ne kadarının gerçekten pozitif olduğunu ölçer(Sokolova ve Lapalme, 2009).

$$\text{Precision} = \frac{\text{TP}}{\text{TP}+\text{FP}} \qquad \text{Denklem 2}$$

Duyarlılık (Recall/Sensitivity): Gerçek pozitiflerin ne kadarının doğru tespit edildiğini ölçer(Sokolova ve Lapalme, 2009).

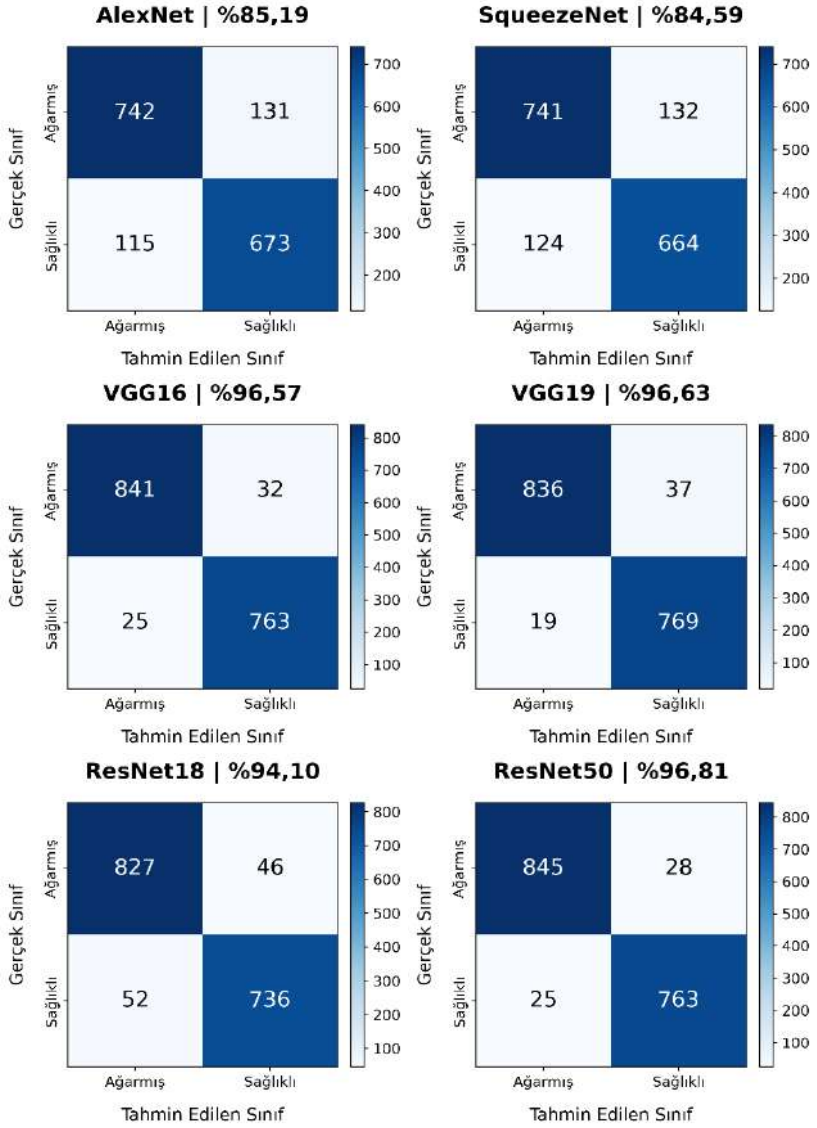
$$\text{Recall} = \frac{\text{TP}}{\text{TP+FN}} \qquad \text{Denklem 3}$$

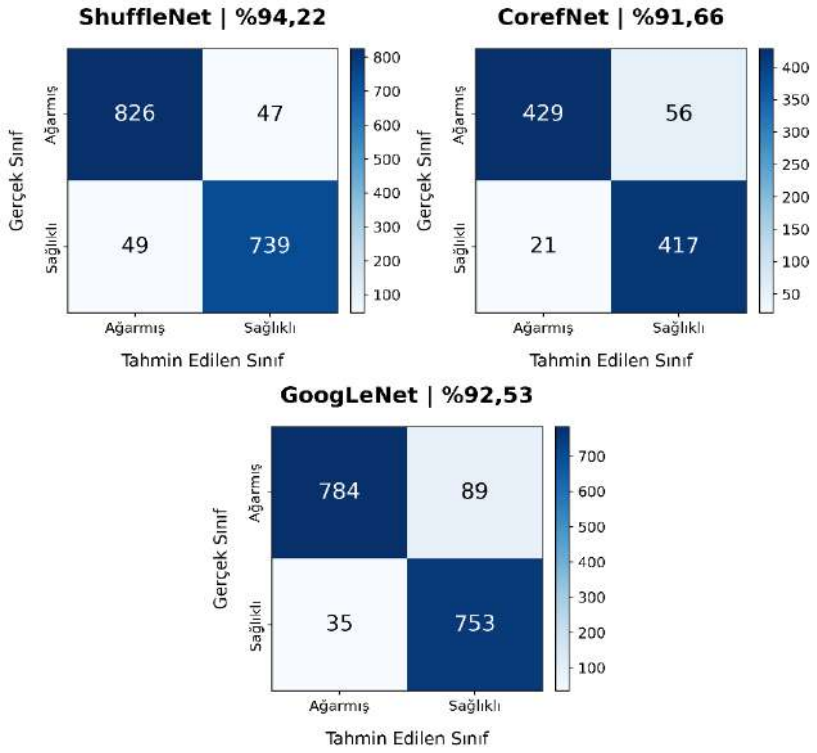
F1-Skor: Kesinlik ve duyarlılığın harmonik ortalamasıdır(Sokolova ve Lapalme, 2009).

$$\text{F1} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision+Recall}} \qquad \text{Denklem 4}$$

4. Sonuçlar

Bu araştırma kapsamında, farklı mimarilere sahip dokuz derin öğrenme ağının (sekiz önceden eğitilmiş ve bir sıfırdan tasarlanmış) mercan sağlığını tespit etme yetenekleri test edilmiştir. Değerlendirme aşamasında, eğitim sürecinde hiç kullanılmamış olan test görüntüleri sisteme verilmiş ve modellerden elde edilen kararlar ile gerçek sonuçlar çaprazlanarak incelenmiştir. Modellerin sınıflandırma kabiliyetleri, hata oranları ve çalışma sürelerine dair elde edilen tüm bulgular şekil 4'te verilmiştir.





Şekil 4. Dokuz Modelin karışıklık matrisleri (confusion matrix).

4.1 Performans Tablosu ve Genel Değerlendirme

Tüm modellerin doğruluk, hassasiyet, geri çağırma ve F1-skoru üzerinden sergiledikleri genel performans Tablo 4'te sunulmaktadır. Tablodaki veriler incelendiğinde, ResNet-50'nin %96,81 doğruluk ve %97,13 hassasiyet ile yüksek başarım elde ettiği görülmüştür. VGG-19 %96,63 doğruluk ile ikinci en iyi başarılı sonuçları elde etmiştir. VGG-16 ise %96,57 doğruluk elde etmiştir. Ayrıca ResNet-18 %94,10 ve ShuffleNet %94,22 doğruluk oranlarıyla yüksek bir performans sergilerken, GoogLeNet de %92,53 başarım oranı sağlamıştır.

Sıfırdan eğitilen CorefNet modelinin elde ettiği sonuçlar umut vadedicidir. Herhangi bir ImageNet ağırlığından yararlanmaksızın, tamamen mercan fotoğraflarıyla sıfırdan öğrenen CorefNet, %91,66 doğruluk ve %91,76 F1-skoru elde etmiştir. AlexNet %85,19 ve SqueezeNet %84,59 doğruluk elde etmiştir. Diğer modellerde ise ResNet-18 %94,10, ResNet-50 %96,81, ShuffleNet %94,22 ve GoogLeNet %92,53 performanslarına ulaşamıştır. CorefNet'in hassasiyet skorunun %95,33 gibi yüksek bir seviyeye ulaşması, modelin "ağarmış" sınıfındaki mercanların büyük çoğunluğunda doğru tahmin ettiğini göstermiştir. Bu durum, özgün olarak tasarlanan Omni-Vision bloklarının ve CorefFusion mekanizmasının, ImageNet ön bilgisi olmadan bile mercan dokusundaki ince renk geçişlerini başarıyla öğrenebildiğini ortaya koymaktadır.

AlexNet ve SqueezeNet ise nisbeten daha düşük başarımlı sonuçlar üretmiştir. ResNet ailesi ResNet-18 ve ResNet-50 ile ShuffleNet sırasıyla %94,10, %96,81 ve %94,22 doğruluk oranlarıyla derin öğrenmenin güncel kapasitesini yansıtan çok daha başarılı sonuçlar üretmiştir. Aralarında parametre sayısı açısından yüksek fark olmasına rağmen her ikisi de birbirine yakın doğruluk oranlarına ulaşmıştır. Bu durum mercan sınıflandırmasında ince ayrım gerektiren görevlerde salt parametre sayısının değil, mimari tasarımın belirleyici olduğunu ortaya koymaktadır.

Tablo 4. Modellerin genel performans karşılaştırması.

Model Mimarisi	Accuracy (Doğruluk)	Precision (Hassasiyet)	Recall (Geri Çağırma)	F1-Score (F1-Skoru)	Eğitim Süresi
AlexNet	%85,19	%86,58	%84,99	%85,78	17 dk 41 sn
SqueezeNet	%84,59	%85,66	%84,88	%85,27	13 dk 58 sn
GoogLeNet	%92,53	%92,58	%92,68	%92,53	27 dk 09 sn
CorefNet	%91,66	%95,33	%88,45	%91,76	67 dk 12 sn
ResNet-18	%94,10	%94,08	%94,73	%94,41	21 dk 28 sn
ResNet-50	%96,81	%97,13	%96,79	%96,96	75 dk 21 sn
ShuffleNet	%94,22	%94,40	%94,62	%94,51	80 dk 32 sn
VGG-16	%96,57	%97,11	%96,33	%96,72	143 dk 50 sn
VGG-19	%96,63	%97,78	%95,76	%96,76	152 dk 32 sn

4.2 Sınıflandırma Detayları ve Hata Analizi

Karışıklık matrisi (confusion matrix) üzerinden yapılan sınıflandırma detayları incelendiğinde, modellerin hangi fotoğraf tiplerinde daha çok zorlandığına dair tespitler ortaya çıkmıştır. Doğada ağarma süreci her zaman bembeyaz bir renk değişimi şeklinde gerçekleşmemekte. Bu süreç kimi zaman mercanlar sadece hafifçe soluklaşabilmektedir. Bu noktada ağın derinliği kritik bir avantaj sağlamıştır.

VGG-19 modeli, sağlıklı mercanları teşhis etme konusunda yüksek bir performans sergilemiş ve test very kümesindeki sağlıklı mercanların çok büyük bir kısmını doğru sınıflandırarak yanlış alarm oranını (False Positive) en aza indirgemiştir. Buna karşın VGG-16 modeli, hasta yani ağarmış mercanları sınıflandırılmasında yüksek başarı elde etmiştir. False Negative oranını oldukça düşük sonuç elde etmiştir. Ekolojik bir kriz anında, ağarmış bir bölgeyi gözden kaçırmak (hasta bir mercana sağlıklı demek) genellikle yanlış alarm vermekten daha risklidir. VGG-16'nın bu spesifik alandaki saha uygulamaları için ekstra bir değer taşımaktadır. Benzer şekilde ResNet-50 de %96,79'luk yüksek geri çağırma oranıyla ağarmış mercanları tespit etmiştir. ResNet-50'nin elde ettiği sonuçlar VGG-16'ya çok yakın ve güvenilir bir performans göstermiş, ResNet-18 ve ShuffleNet de %94 ise gerçek zamanlı uygulamalar için potansiyel taşıdığını göstermektedir.

CorefNet modeli ise kendine özgü bir yapı yer almaktadır. Sağlıklı mercanları tanımada yüksek bir başarı gösterirken yalnızca 21 yanlış pozitif üretmiştir. Ağarmış mercanları tespit etmede 56 adet sahte negatif üreterek geri çağırma oranı %88,45'te kalmıştır. Bu durum, CorefNet'in hafif ağarmaya uğramış bazı geçiş formlarında temkinli davrandığını ve bunları sağlıklı olarak etiketleme eğiliminde olduğunu göstermektedir. Yine de hiçbir önceden eğitilmiş ağırlık kullanmadan elde edilen %95,33'lük hassasiyet, modelin "ağarmış" dediği tahminlerde yüksek doğruluk elde etme potansiyeli taşımaktadır.

Buna karşılık AlexNet ve SqueezeNet, renk geçişlerinin çok ince olduğu ara formlardaki mercan fotoğraflarında kafa karışıklığı yaşamıştır. Her iki model de hem sağlıklıları ağarmış zannetme hem de ağarmışları gözden kaçırma konusunda %15'lerin altına inememiş, bu da sığ ağların mercan dokusundaki o ince detayı ve mikroskobik renk solmalarını yakalamada yetersiz kaldığını göstermiştir. Ancak daha gelişmiş özellik çıkarma kapasitesine sahip ResNet-18, ResNet-50 ve ShuffleNet

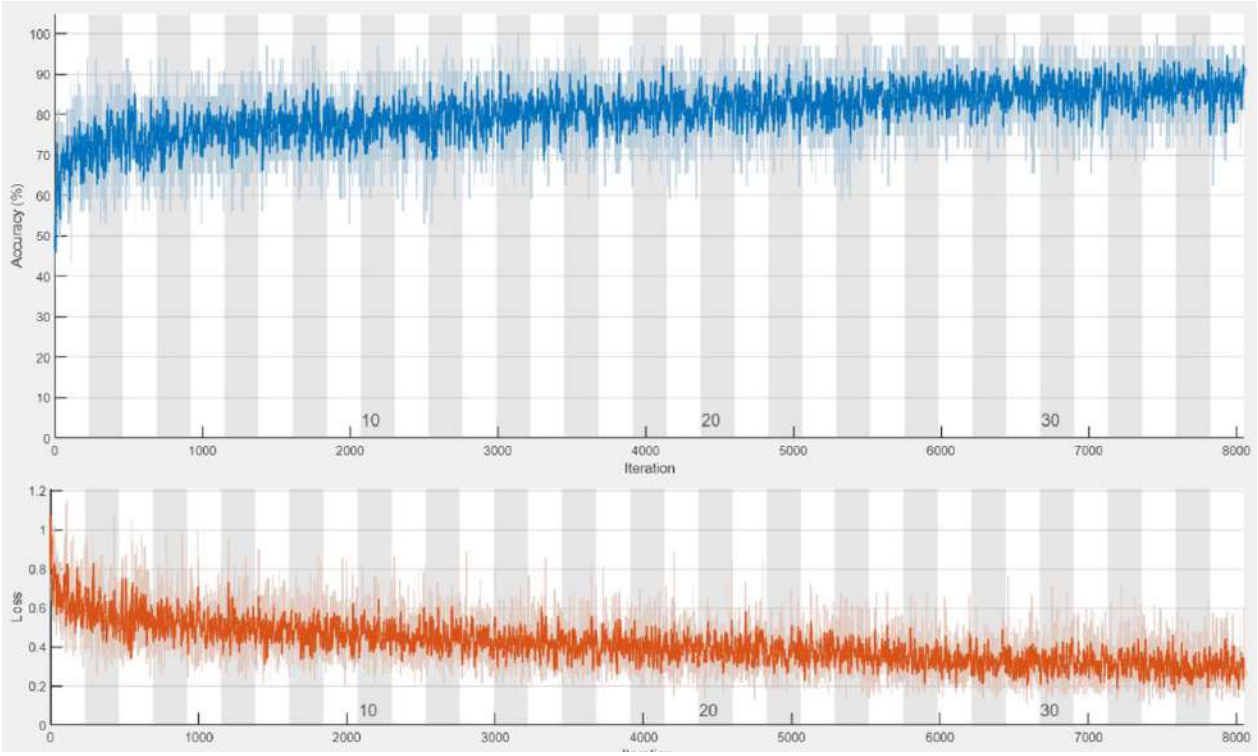
mimarileri, tıpkı VGG ağları gibi bu ince detayları ve mikroskobik solmaları başarıyla öğrenerek hata oranları düşük bir seviyede seyretmiştir.

4.3 Öğrenme Eğrileri ve Kaynak Tüketimi

Eğitim süreci boyunca modellerin nasıl bir öğrenme grafiği (learning curve) çizdiğini ve kaynakları nasıl kullandığını incelemek, sistemlerin donanımsal verimliliklerini anlamak açısından önemlidir.

Süreci grafiksel olarak ele aldığımızda, VGG-16 ve VGG-19 modellerinin ilk 2.000 iterasyondan itibaren çok hızlı bir şekilde öğrenme eğrisini tırmandığı ve ilerleyen turlarda hata oranını neredeyse sıfıra doğru çekerek istikrarlı bir şekilde stabilize olduğu görülmüştür. VGG-19 modeli içerdiği yoğun katmanlar nedeniyle eğitimi tamamlamak için 152 dakikaya ihtiyaç duyarken, VGG-16 yaklaşık 143 dakikada süreci noktalamıştır. Model atlama bağlantılarıyla (residual connections) öğrenmeyi hızlandıran ResNet-50, yüksek bir doğruluğa ulaşmış ve eğitim 75 dakikada tamamlamıştır. ResNet-18 ise 21 dakikada, GoogLeNet 27 dakikada, ShuffleNet de 80 dakikada eğitimlerini bitirerek modern mimarilerin zaman ve kaynak verimliliğindeki üstünlüklerini ortaya koymuştur.

CorefNet'in eğitim grafiği incelendiğinde, ilk birkaç yüz iterasyonda doğruluğun hızla %70-75 bandına tırmandığı, ardından yaklaşık 2.000 iterasyona kadar %80-85 aralığında dalgalandığı görülmüştür. Sonraki epoch'larda model kademeli olarak %90 civarına yerleşmiş ve eğitim sonunda kayıp değeri başlangıçtaki ~1,0 seviyesinden ~0,3'e gerilemiştir. Adam optimizasyon algoritmasının kullanılması ve her 12 epoch'ta öğrenme oranının yarıya düşürülmesi, sıfırdan eğitim sürecinin kararlılığına belirgin bir katkı sağlamıştır. Toplam 67 dakika 12 saniyelik eğitim süresiyle CorefNet, VGG ailesinin yarısından az bir sürede eğitimini tamamlamıştır. Modelin eğitim grafiği şekil 5'te verilmiştir.



Şekil 5. CorefNet eğitim grafiği

AlexNet ve SqueezeNet modellerinin eğitim süreçleri incelendiğinde hızlı bir öğrenme ivmesi yakalasalar da, sınırlı parametre kapasitelerinden dolayı bir noktadan sonra "öğrenme tavanına" vardıkları görülmüştür. Ancak burada SqueezeNet yalnızca 1,2 milyon parametreyle çalışmasına rağmen AlexNet'in 60 milyonluk parametresiyle tüm eğitimini sadece 13 dakika 58 saniyede tamamlamıştır.

5. Tartışma ve Gelecek Çalışmalar

5.1 Tartışma

Mercanlardaki ağarma süreci sadece hafif bir renk solması şeklinde kendini gösterebilmektedir. Bu ince ayrıntıları algılayabilmek için ağ mimarisinin öznitelikleri öğrenebilen bir yapıda olması gerekmtektedir. VGG-19 ile VGG-16 doğruluk açısından nisbeten düşük bir fark %0,06 bulunmaktadır. Ancak VGG-19 sistemi yaklaşık 10 dakika daha fazla sürmüştür. Zamanın ve işlemci gücünün değerli olduğu gerçek saha uygulamalarında, doğruluk kaybını göze alıp VGG-16'yı kullanmak çok daha mantıklı bir tercih olabilir. %96,81 doğruluk ve sadece 75 dakikalık eğitim süresiyle ResNet-50, her iki VGG modeline kıyasla donanım kaynaklarını çok daha efektif kullanan optimum bir tercih olarak öne çıkmaktadır.

Sıfırdan eğitilen CorefNet'in elde ettiği %91,66'lık doğruluk oranıdır. Hiçbir ImageNet ağırlığından yararlanmadan, yalnızca mercan fotoğraflarıyla eğitilen bu model, 60 milyon parametreli AlexNet'i yaklaşık %6,5, 1.2 milyon parametreli SqueezeNet'i ise %7 oranla daha iyi performans sergilemiştir. Bu sonuç, probleme özgü tasarlanan bir mimarinin (Omni-Vision blokları ve CorefFusion mekanizması) hazır fakat genel amaçlı ağlardan daha etkili olabileceğini göstermektedir. Öte yandan CorefNet'in VGG ailesinin ve modern mimarilerin ResNet, ShuffleNet gibi, gerisinde kalması %91,66'ya karşı %94-%96, ImageNet'te edinilmiş milyonlarca düşük ve orta seviye görsel filtrenin transfer öğrenme aracılığıyla getirdiği avantajın hâlâ göz ardı edilemez bir düzeyde olduğunu ortaya koymaktadır.

AlexNet ve SqueezeNet'in başarım oranları ise oldukça yakın olduğu gözlemlenmiştir. Aralarında parametre farkı olmasına rağmen aynı skoru almaları, mercan sınıflandırması gibi ince ayrım gerektiren görevlerde parametre sayısından ziyade mimari tasarımın belirleyici olduğuna işaret etmektedir. Su altı dronunun çipine bu yapay zekayı sığdırmak, SqueezeNet'in o hafifliğine rağmen %85 doğruluk vermesi cazip bir seçenek olarak dursa da, CorefNet'in 6,5 milyon parametreyle %91,66'ya ulaşması gömülü sistemler için çok daha dengeli bir alternatif sunmaktadır. Tüm bunlara ek olarak, mobil cihazlar için optimize edilmiş mimarisiyle ShuffleNet'in yalnızca 1,4 milyon parametre kullanarak %94,22 doğruluğa ulaşması, gömülü sistemler ve kısıtlı donanımlı dronlar için tartışmasız en güçlü seçeneğin ShuffleNet olduğunu kanıtlamaktadır. GoogLeNet ise hız ve performans dengesi ile dikkate değer bir alternatif olarak konumlanmaktadır (Doğan ve ark., 2025).

Bu bulgular, geçmiş yıllardaki benzer çalışmaların ortaya koyduğu tezlerle uyuşmaktadır. Elmezain vd. (Elmezain ve ark., 2026) tarafından kullanılan karmaşık otonom yazılımlara kıyasla, hazır modellerin ufak dokunuşlarla bu kadar iyi iş çıkarması, doğa korumacıların elini güçlendirecek pratik bir alternatiftir. Ayrıca Hughes vd.(Hughes ve ark., 2017) ve Welle vd.(Welle ve ark., 2017) gibi çalışmalarda belirtilen "mercanlar yok oluyor" çağrılarına bilgisayar destekli karar sistemlerinin katkı sağlayacağı düşünülmektedir.

5.2 Gelecek Adımlar

Araştırmayı daha ileriye taşımak ve gelecekte yapılabilecekler çalışmalar şu şekilde verilebilir:

1. Sadece "sağlıklı" veya "hasta" demek yerine, Zamani ve Madduppa (Zamani ve Madduppa, 2011) metodolojisine uygun olarak, hasarın boyutunu evre evre algılayan sistemler tasarlanabilir.

2. EfficientNet, ConvNeXt, Vision Transformer, Swin Transformer gibi güncel algoritmalar çalışmaya dahil edilerek skorlar daha da yukarı çekilebilir (Aktaş ve ark., 2026).

3. Chariyev vd.(Chariyev ve ark., 2025) veya Hafizt vd.(Hafizt ve ark., 2023) tarafından uydu verileriyle yapılan araştırmalar, bu tür su altı yakından çekilmiş görüntülerle eşleştirilerek mükemmel bir erken uyarı sistemi inşa edilebilir.

4. "Bu model mercanın ağardığını söylüyor ama neye bakarak söylüyor?" sorusunu gidermek için, yapay zekanın baktığı noktaları ısı haritasıyla gösteren şeffaf teknolojiler (Grad-CAM vb.) eklenebilir. Böylece biyologların bu yazılımlara olan güveni artırılabilir.

5. Her ne kadar bu çalışma görüntü tabanlı mercan sınıflandırmasına odaklanmış olsa da, kullanılan derin öğrenme yaklaşımlarının farklı biyolojik veri türlerine uygulanma potansiyeli

bulunmaktadır. Bu kapsamda, araştırma endemik Ornithogalum yesilyurtense ve Ornithogalum yildirimlii bitki türleri üzerinde yürütülen fitokimyasal karakterizasyon çalışmalarında elde edilen çok değişkenli biyolojik verilerin yapay zekâ ve derin öğrenme tabanlı yöntemlerle değerlendirilmesi, gelecekte gerçekleştirilecek ayrı çalışmalarla araştırılabilir (Demir Perçin et al., 2026a, 2026b).

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RHUS CORİARİA L. EKSTRAKTININ BİYODİZEL–DİZEL YAKIT KARIŞIMLARININ DÜŞÜK SICAKLIK KRİSTALLEŞME DAVRANIŞI ÜZERİNDEKİ ETKİSİNİN İNCELENMESİ

EFFECT OF *RHUS CORİARİA* L. EXTRACT ON THE LOW-TEMPERATURE CRYSTALLİZATİON BEHAVİOR OF BİODİESEL–DİESEL FUEL BLENDS

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ÖZET

Rhus coriaria L. Ekstraktının Biyodizel–Dizel Yakıt Karışımlarının Düşük Sıcaklık Kristalleşme Davranışı Üzerindeki Etkisinin İncelenmesi

Fosil yakıtların neden olduğu çevresel sorunlar ve artan enerji gereksinimi, yenilenebilir ve sürdürülebilir yakıt alternatiflerinin geliştirilmesine yönelik araştırmaları hızlandırmıştır. Bu kapsamda biyodizel; yenilenebilir kaynaklardan üretilebilmesi, biyolojik olarak parçalanabilirliği ve dizel yakıtlarla farklı oranlarda kullanılabilmesi nedeniyle önemli bir alternatif yakıt olarak değerlendirilmektedir. Bununla birlikte, biyodizelin içerdiği uzun zincirli yağ asidi metil esterleri düşük sıcaklıklarda kristal oluşumunu kolaylaştırarak yakıtın akış özelliklerini ve kullanım performansını sınırlandırabilmektedir. Bu nedenle, biyodizel esaslı yakıtların düşük sıcaklık davranışını iyileştirebilecek doğal ve sürdürülebilir katkı maddelerinin araştırılması önem taşımaktadır.

Bu çalışmada, fenolik ve diğer biyoaktif bileşenler açısından zengin bir bitkisel kaynak olan sumak (*Rhus coriaria* L., Anacardiaceae) ekstraktının biyodizel–dizel yakıt karışımlarında doğal katkı maddesi olarak kullanım potansiyeli araştırılmıştır. Biyodizel ve dizel yakıt hacimce %40:%60 oranında karıştırılmış ve hazırlanan yakıt matrisine *R. coriaria* ekstraktı 3000 ppm konsantrasyonda ilave edilmiştir. Karşılaştırma amacıyla askorbik asit aynı konsantrasyonda referans katkı maddesi olarak kullanılmıştır. Katkısız ve katkılı yakıt formülasyonlarının termal davranışları ve kristalleşme özellikleri diferansiyel taramalı kalorimetri (DSC) yöntemiyle karşılaştırmalı olarak değerlendirilmiştir.

DSC bulguları, *R. coriaria* ekstraktının ilavesiyle biyodizel–dizel karışımının kristalleşme başlangıç sıcaklığının daha düşük sıcaklık bölgesine kaydığını göstermiştir. Bu davranış, ekstraktta bulunan doğal bileşenlerin yakıt matrisi içerisindeki moleküler düzenlenme, kristal çekirdeklenmesi ve kristal büyüme süreçleri üzerinde etkili olabileceğini düşündürmektedir. Referans katkı maddesiyle yapılan karşılaştırma da sumak ekstraktının düşük sıcaklık performansının iyileştirilmesi açısından umut verici bir etki sergilediğini ortaya koymuştur.

Sonuç olarak, *Rhus coriaria* L. ekstraktının biyodizel–dizel sistemlerinde kristalleşme davranışını modifiye edebilecek doğal ve bitkisel kökenli fonksiyonel bir yakıt katkısı adayı olduğu belirlenmiştir.

Anahtar Kelimeler: *Rhus coriaria* L.; biyodizel–dizel karışımı; doğal katkı maddesi; DSC; düşük sıcaklık kristalleşmesi

ABSTRACT

Environmental concerns associated with fossil fuel consumption and the increasing global energy demand have accelerated research into renewable and sustainable fuel alternatives. In this context, biodiesel is regarded as an important alternative fuel due to its renewable origin, biodegradability, and compatibility with diesel fuel at various blending ratios. However, the long-chain fatty acid methyl esters present in biodiesel can promote crystal formation at low temperatures, thereby impairing fuel flow

properties and limiting operational performance. Therefore, considerable attention has been directed toward identifying natural and sustainable additives capable of improving the low-temperature behavior of biodiesel-based fuels.

In this study, the potential use of sumac (*Rhus coriaria* L., Anacardiaceae), a plant source rich in phenolic and other bioactive constituents, as a natural additive in biodiesel–diesel fuel blends was investigated. Biodiesel and diesel fuel were blended at a volumetric ratio of 40:60, and *R. coriaria* extract was incorporated into the resulting fuel matrix at a concentration of 3000 ppm. For comparison, ascorbic acid was used as a reference additive at the same concentration. The thermal behavior and crystallization characteristics of the untreated and additive-containing fuel formulations were comparatively evaluated using differential scanning calorimetry (DSC).

The DSC results showed that the addition of *R. coriaria* extract shifted the crystallization onset temperature of the biodiesel–diesel blend toward lower temperatures. This behavior suggests that naturally occurring constituents present in the extract may influence molecular organization within the fuel matrix, as well as crystal nucleation and crystal growth processes. Comparison with the reference additive further demonstrated that sumac extract exhibited a promising effect on improving the low-temperature performance of the fuel blend.

In conclusion, *Rhus coriaria* L. extract was identified as a promising natural, plant-derived functional additive capable of modifying the crystallization behavior of biodiesel–diesel fuel systems.

Keywords: *Rhus coriaria* L.; biodiesel–diesel blend; natural additive; DSC; low-temperature crystallization

TOWARDS SCIENTIFIC INDEPENDENCE AND REGIONAL INTEGRATION: A VISION FOR ESTABLISHING THE ARAB-ISLAMIC ARCHAEOBOTANICAL RESEARCH LABORATORY

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ABSTRACT

The Arab and Islamic world possesses an extraordinary wealth of archaeological sites spanning the cradles of early agriculture, including the Fertile Crescent, the Nile Delta, and the Arabian Peninsula. Despite this rich heritage, the region faces a critical technological gap, remaining largely dependent on Western institutions for analyzing botanical remains such as charred seeds, pollen (palynology), phytoliths, and ancient plant DNA. This research outlines a comprehensive framework for establishing the first dedicated Arab-Islamic Archaeobotanical Research Laboratory, aimed at fostering scientific autonomy, preserving regional bio-cultural heritage, and building local competitive research capacity to international standards.

Operational and Financial Architecture

The proposed initiative relies on a strategic division of capabilities across the region:

- Financial & Infrastructure Investment (GCC States): Providing core funding for advanced laboratory equipment, including Scanning Electron Microscopy (SEM), Accelerator Mass Spectrometry (AMS) for radiocarbon dating, and specialized ancient DNA (aDNA) extraction facilities.
- Human Capital & Fieldwork Support (Broader Arab & Islamic Nations): Contributing qualified researchers, academic staff, and volunteers to lead field sampling, conduct excavations, and execute laboratory analyses.

Strategic Objectives & Scope

- Establishing a Regional Reference Collection: Developing the comprehensive database and herbarium of ancient seeds and botanical specimens for the Arab and Islamic world.
- Decoding Historical Agriculture & Climate Adaptation: Analyzing ancient crop domestication and historical climate resilience to inform modern food security strategies using ancestral genetic traits.
- Global Academic Leadership: Transitioning the region from a supplier of raw samples to an international research hub that offers analytical services, training, and equitable academic partnerships.

This initiative transcends conventional historical documentation; it represents a strategic step toward regional knowledge sovereignty. By bridging funding capabilities with scientific expertise, the project establishes a self-sustaining paradigm that positions the Arab and Islamic scientific community as a leader in global archaeobotanical research.

Key words: Archaeobotany, Excavations, Lab, Documentation, South Levant.

PREDICTION OF CHLORINE DOSE IN A DRINKING WATER TREATMENT PLANT USING ARTIFICIAL NEURAL NETWORKS: APPLICATION TO BENI ZID STATION, SKIKDA, ALGERIA

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ABSTRACT

Accurate control of chlorine dosage is essential for maintaining drinking water quality and ensuring effective disinfection. The required chlorine dose is influenced by several physicochemical parameters, making its prediction a complex nonlinear problem. In this study, an Artificial Neural Network (ANN) model was developed to predict the chlorine dose at the Beni Zid drinking water treatment plant in Skikda, Algeria. Five water-quality parameters were considered as input variables: temperature (T), total dissolved solids (TDS), electrical conductivity (EC), pH, and turbidity (TUR), while the chlorine dose (CHL) was considered as the output variable. The available experimental data were used to develop and evaluate the neural-network model through training, validation, and testing phases. The results showed that the ANN approach provided encouraging predictive performance and was more effective than the Multiple Linear Regression model for describing the relationship between water-quality parameters and chlorine requirements. The correlation coefficient exceeded 0.65 during the testing phase and reached approximately 0.78 during the validation phase. These results demonstrate the potential of artificial neural networks as a useful decision-support tool for predicting chlorine demand and improving the management of drinking-water disinfection. Further improvement could be achieved by using a larger database and optimizing the network architecture and training parameters.

Keywords: Artificial neural networks; Chlorine dose; Drinking water; Water treatment plant; Prediction; Water quality; Skikda.

TÜRKİYE'DE AKADEMİK GÖÇÜN ÇİFT YÖNLÜ SEYRİ (1933–1950)

THE TWO-WAY COURSE OF ACADEMIC MIGRATION IN TURKEY (1933–1950)

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ÖZET

1933 Üniversite Reformu, Türk yükseköğretim tarihinde dönüşümün yanı sıra Nazi Almanyası'ndan kaçan bilim insanlarına kapı açmasıyla anılmaktadır. Bu çalışma, aynı düzenlemenin eşzamanlı ikinci bir yönü bulunduğu düşüncesinden hareket etmektedir. Darülfünun kadrosunun önemli bir bölümünün üniversite dışında bırakıldığı 1933 Üniversite Reformu, yabancı bilim insanlarının kabulü ile yerli kadroların tasfiyesini birbirine bağlamıştır. Çalışma 1933-1950 dönemini akademik personel dolaşımı ekseninde ele almakta ve genellikle ayrı ayrı anlatılan iki hareketi birlikte okumaya çalışmaktadır. Bir yanda Kessler, Hirsch ve Ruben gibi isimlerin Türkiye'ye gelişi, kürsü kuruculukları ve kurumsal düzenlemelerdeki rolleri, öte yanda 1933'te kadro dışı bırakılan müderrisler ile 1948 Dil ve Tarih-Coğrafya Fakültesi tasfiyesinin ardından Berkes'in Kanada'ya, Muzaffer Şerif'in Amerika Birleşik Devletleri'ne ve Boratav'ın Fransa'ya gidişi yer almaktadır. İki hareketin kesiştiği tarih ise 1948'dir. Aynı tasfiye dalgasında Alman bilim insanlarının kadrolarının da kaldırılması, Ruben'in savaş yıllarında Kırşehir'de zorunlu ikamete tabi tutulması ve ardından Şili'ye yerleşmesi, sığınma ile sürgünün aynı kadro politikasının farklı görünümleri olduğunu düşündürmektedir. 1950 sonrasında Alman akademisyenlerin yerini Amerikalı uzmanların alması ise bu işleyişin dış siyasal yönelimle ilişkisini göstermektedir. Çalışmanın temel yaklaşımı, dönemin akademik kadro kararlarının bilimsel liyakat ölçütlerinden çok konjonktürel siyasal yönelimle şekillendiği yönündedir. Üniversiteyi bir sığınak hâline getiren düzenlemeler ile onu bir sürgün kaynağına dönüştüren uygulamalar birbirinin karşıtı değil, aynı kadro politikasının iki görünümü olarak değerlendirilmektedir. Türkiye'nin bu dönemde yalnızca sürgün kabul eden değil aynı zamanda sürgün üreten bir ülke olması, akademik göçün çift yönlü seyrini görünür kılmakta ve mevcut değerlendirmelerin yeniden ele alınmasını gerekli kılmaktadır. Bu çerçevede çalışma, 1933 reformunu yalnızca bir modernleşme başarısı olarak okuyan anlatıya ve yabancı bilim insanlarının katkısını Türkiye'deki tasfiye pratiğinden ayrı ele alan literatüre eleştirel bir katkı sunmayı amaçlamaktadır.

Anahtar Kelimeler: 1933 Üniversite Reformu, yükseköğretim tarihi, akademik göç, üniversite özerkliği, 1948 DTCF tasfiyesi,

ABSTRACT

The University Reform of 1933 is remembered in the history of Turkish higher education not only for the transformation it brought about but also for opening the door to scholars fleeing Nazi Germany. This study proceeds from the idea that the same measure had a second, simultaneous dimension. The 1933 University Reform, through which a substantial portion of the Darülfünun teaching staff was left outside the university, linked the admission of foreign scholars to the dismissal of local academic staff. The study examines the period between 1933 and 1950 along the axis of academic personnel mobility and seeks to read together two movements that are generally recounted separately. On the one hand, there is the arrival in Turkey of figures such as Kessler, Hirsch and Ruben, their establishment of chairs and their role in institutional arrangements; on the other, there are the müderrises (Darülfünun professors) excluded from the academic cadre in 1933, along with the departure of Berkes for Canada, Muzaffer Şerif for the United States of America and Boratav for France following the 1948 purge at the Faculty of Language, History and Geography. The year in which these two movements intersect is 1948. The removal of the posts of German scholars during the same wave of dismissals, together with Ruben's

being subjected to compulsory residence in Kırşehir during the war years and his subsequent settlement in Chile, suggests that refuge and exile were different manifestations of the same staffing policy. The replacement of German academics by American experts after 1950, in turn, demonstrates the relationship between this process and the country's external political orientation. The study's basic approach is that the academic staffing decisions of the period were shaped less by criteria of scholarly merit than by conjunctural political orientation. The arrangements that turned the university into a place of refuge and the practices that made it a source of exile are assessed not as opposites but as two manifestations of the same staffing policy. That Turkey in this period was not only a country receiving exiles but also one producing them makes visible the two-way course of academic migration and necessitates a reconsideration of prevailing assessments. Within this framework, the study aims to offer a critical contribution to the narrative that reads the 1933 reform solely as a success of modernisation and to the literature that treats the contribution of foreign scholars separately from the practice of dismissal in Turkey.

Keywords: 1933 University Reform, History Of Higher Education, Academic Migration, University Autonomy, 1948 DTCF Purge.

SEMICONDUCTOR WAFER PATTERN RECOGNITION USING GHOSTNET: BALANCING ACCURACY AND PARAMETER EFFICIENCY

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ABSTRACT

In semiconductor factories, the automated diagnosis of silicon chip failures using Industry 4.0 has become crucial. Early detection of failures on silicon wafers in semiconductor materials offers benefits such as increased end-user satisfaction and reduced costs. A lightweight and highly accurate study was conducted to detect failures on silicon wafers using lightweight and efficient deep learning models. In our study, nine different failure types (Center, Donut, Edge-Loc, Edge-Ring, Local, Near-Full, Normal, Random, and Scratch) were detected with a total of 5616 image datasets using high-accuracy GhostNet transfer learning and fine-tuning. This was achieved through the Ghost module, which eliminated redundancies in the feature maps of the classical convolution layer and utilized depthwise separable convolution. Furthermore, the Squeeze-and-Excitation module dynamically highlighted the most prominent feature channels. The designed GhostNet model achieved extremely low computational complexity with only 158,330 parameters, a model size of 0.60 MB, and 23.546 million FLOPs. Experimental studies yielded 98.97% train accuracy and 99.29% validation accuracy, supported by T-SNE visualizations, ROC curve, and confusion matrix results.

Keywords: GhostNet Architecture, Semiconductor Manufacturing, Wafer Defect Classification.

INTRODUCTION

The semiconductor industry is one of the most critical elements in many different sectors such as consumer electronics, the automotive sector, and aerospace technology. These production processes involve precise physical and chemical stages. Even the smallest deviations on the production lines can cause failures on silicon wafers. Surface defects on silicon wafers can hinder the functionality of integrated circuits and prevent the electrical conductivity of chips. When all these factors are considered together, the product yield decreases significantly. The failure to detect faulty wafers on the production line and their subsequent processing leads to more expensive processes, resulting in significant economic losses. The need for automated quality control systems in wafer production lines is also evident. Since almost dozens of products are processed per second in semiconductor fabrication, fault diagnosis must be performed at a high speed, within milliseconds.

Traditional fault diagnosis processes are prone to error and are time-consuming because they are carried out using manual diagnostic methods. With the high production speeds and increasing wafer scales in modern factories, traditional fault diagnosis techniques have become insufficient, and the need to automate this process has increased. Traditional image processing and rule-based methods have some shortcomings, such as being able to recognize only predefined geometric patterns and being inadequate for diagnosing newly emerging faults. The recent high performance of deep learning models in fault diagnosis has led to significant research in this area.

Shinde et al. (2022) used public WM-811k wafer 9-class defect dataset to locate and classify defects on silicon wafers. They presented a comparative analysis of the results from YOLOv3 and YOLOv4 architectures. Both architectures achieved accuracy rates above 94%. Although ResNet50 and DenseNet121 architectures were also used for comparison, higher performance was obtained from the YOLO architectures. Zhu and Wu (2026) established a hybrid model for micro-scale wafer surface defects using EfficietnNetV2 and multi-scale self-attention enhancement. Using public wafer defect dataset, they analyzed 15 different defect types and a total of 1,500 images. The results showed 96.60%

accuracy and an 8.14% increase compared to the performance of the classical EfficiencyNetV2 architecture. Akhter et al. Tsai and Wang (2025) developed a new transformer, the Regional-to-Local Attention-based Vision Transformer, for detecting defects on the wafer surface with the miniaturization of integrated circuits. Furthermore, to test their proposed model, they tested it using 38 different defect types on a public wafer defect dataset. This study, which achieved a test accuracy of 98.63%, highlighted the model's robustness against previously uncommon defect types.

Tsai and Wang (2025) found that classification is difficult due to inter-class data sample imbalance and the small number of samples belonging to some defect classes for wafer defect detection. To prevent the dominance of classes containing the majority of samples, they performed random undersampling. They proposed a Global-to-Local Generative Adversarial Network for wafer defect classification. They used MobileNetV2 in the classification layer. They achieved 98.39% classification accuracy on the WM-811K defect wafer dataset containing 21 different defect types. Hwang et al. (2025) also performed wafer defect classification with the same WM-811K dataset in this study. For comparison, ResNEt101 and ViT architectures were tested, achieving 85.32% and 86.58% accuracy respectively, while this study achieved 86.65%. The new model they used in the study involves contrastive learning with label embedding. Lee et al. (2025) performed wafer defect classification with Density-based features and Radon-based features models by extracting CNN-based features. 95.09% accuracy was obtained with ensemble learning and weighted soft voting. As in other studies, the 8-class WM-811K public wafer defect dataset was used.

Ingle et al. (2025) performed wafer defect segmentation and classification. For segmentation, the Mean Absolute Error (MAE) was 0.0036, while the Root Mean Squared Error (RMSE) was 0.0576. An accuracy of 0.9705 was obtained for classification. Geng et al. (2023) conducted a literature review study on wafer defect classification. Recently, machine learning and deep learning-based studies have been widely used. Chien et al. (2020) proposed a CNN-based model for early and accurate detection of wafer defects. A classification score of 98% was obtained for four different defect types: Center, Local, Random, and Scrape defects, by developing a CNN model from scratch. Wu et al. (2024) used the Denoising Diffusion Probabilistic Model (DDPM) for situations where a sufficient number of wafer defect samples were not available. For classification, YOLOv8-cls achieved 98.7% accuracy, and for segmentation, the YOLOv8-seg model achieved 95.7% mask mAP accuracy. Bao et al. (2024) achieved 98.56% classification accuracy with CNN using self-encoder-based data augmentation on the same WM-811K dataset for wafer defect classification. Compared to Random Forest, it achieved approximately 19% higher accuracy. Mohammad and Ryu (2025) achieved 98.4% F1-score with the ViT tiny model on the WM-38k dataset, which is 2.94% higher than ViT-Base.

Table 1. Literature review for drug table defect classification

Study	Method	Dataset	Metrics
Shinde et al. (2022)	YOLOv3, YOLOv4, ResNet50, DenseNet121	WM-811K, 9 classes	Acc. >94%; ResNet50: 89%; DenseNet121: 92%
Zhu and Wu (2026)	EfficientNetV2 + Multi-scale Self-Attention	1,500 images, 15 classes	Acc.: 96.60%; F1: 96.67%
Akhter et al. (2025)	RegionViT	38 mixed-type classes	Acc.: 98.63%
Tsai and Wang (2025)	G2LGAN + MobileNetV2	WM-811K, 21-Defect	Acc.: 98.39%; F1: 93.01%
Hwang et al. (2025)	Label Embedding + Contrastive Learning	WM-811K	Acc.: 86.65%
Lee et al. (2025)	CNN + Density/Radon Features + Ensemble	WM-811K, 8 classes	Acc.: 95.09%; F1: 95.00%
Chien et al. (2020)	CNN	4 classes	Acc.: 98–99%

METHODOLOGY

A balanced architecture is proposed for the automatic classification of defects in semiconductor wafer manufacturing processes, offering low computational complexity, lightweight design, and high accuracy. This model, suitable for industrial applications with limited resources and real-time scenarios, has been trained and tested on datasets such as WM-811K with various defect patterns including Center, Donut, Edge-Loc, Edge-Ring, Local, Random, Scratch, and Near-Full. The model's core component, the Ghost Module, generates some features using standard convolution and derives the remaining features through low-cost processes. Features are extracted using depthwise convolution instead of classical convolution. The Ghost Bottleneck structure, another important component, applies depthwise convolution based on the stride value. Finally, the resulting feature vector is transferred to a fully coupled classification layer.

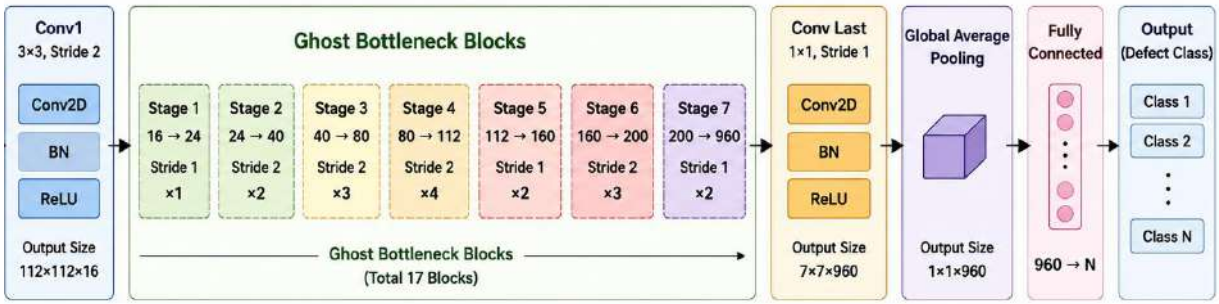

Figure 1. GhostNet overall arcitecture

EXPERIMENTAL RESULTS

In this study, classification metrics, complexity matrix, ROC curve, and classification score for each class were evaluated to assess the performance of the proposed model. To prove that the proposed model is quite lightweight and fast, the EfficientNetB0, MobileNetV2, and ResNet18 architectures, known for their speed in the literature, were compared in terms of model parameter number, model size, computational complexity. Thus, it was revealed that the proposed model is superior to all other models. This study was conducted on a system with a 13th generation Intel Core i7-13620H central processing unit (CPU) and an NVIDIA GeForce RTX 4060 Laptop GPU graphics processing unit (GPU). Figure 2 shows the comparison of the proposed model with other models in the literature.

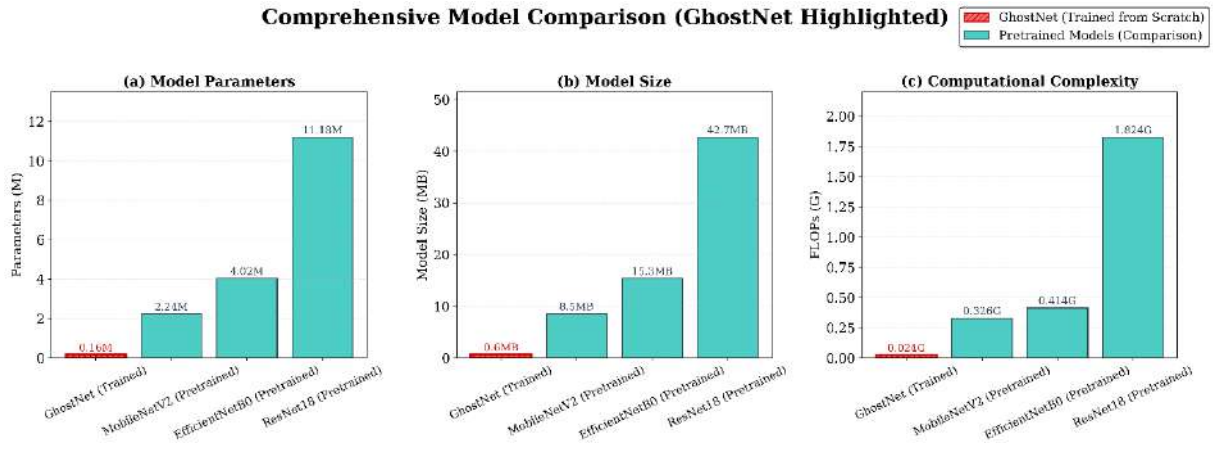

Figure 2. Comprehensive model comparsion

Table 2. Computational cost and inference performance of GhostNet and comparison models

Model	Params (M)	Size (MB)	FLOPs (G)
EfficientNetB0	4.02	15.3	0.414G
MobileNetV2	2.24	8.5	0.326G
ResNet18	11.18	42.7	1.824G
GhostNet	0.16	0.6	0.024G

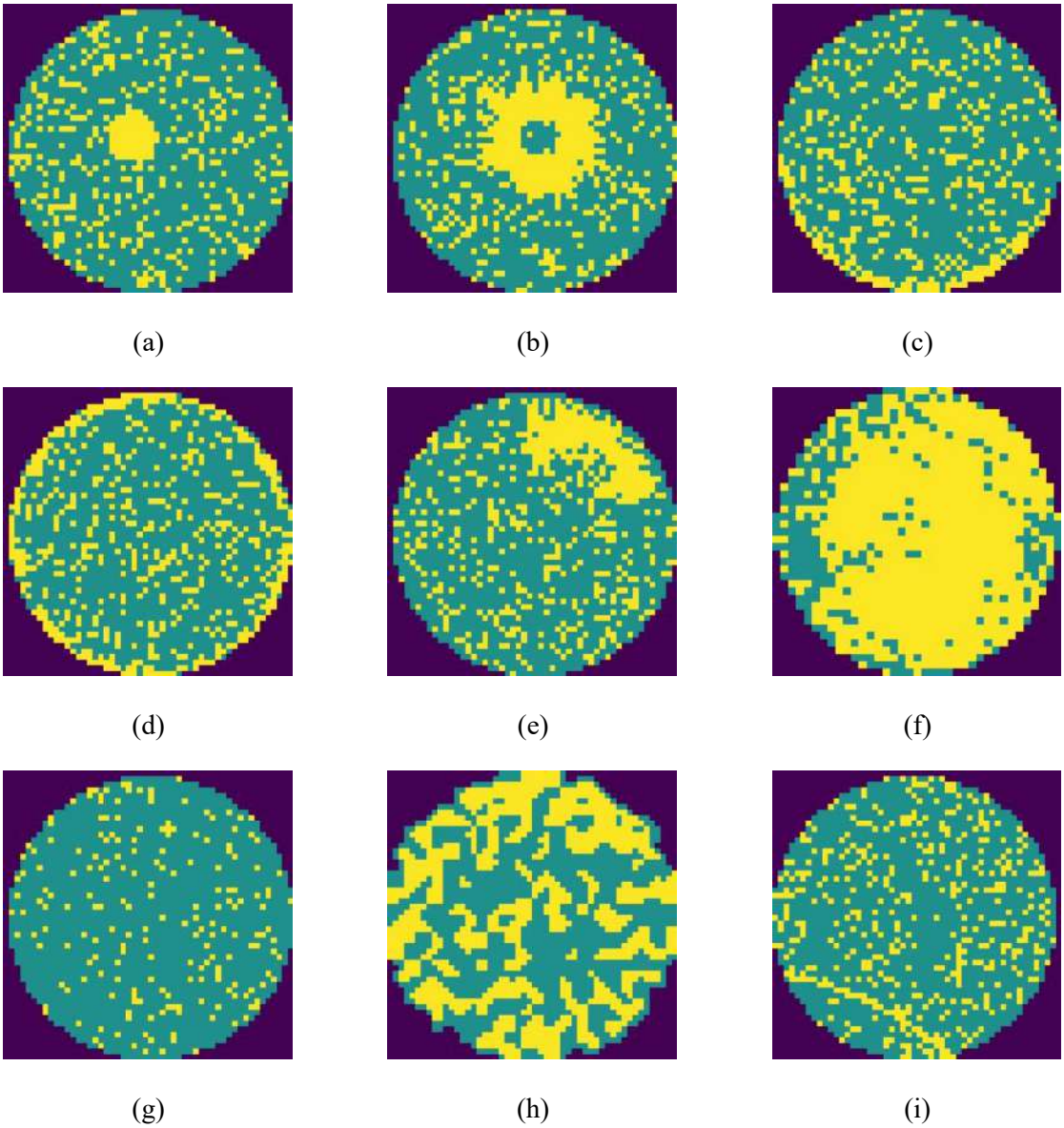

Figure 3. Sample drug images belonging to the categories (a) Center, (b) Donut, (c) Edge-loc, (d) Edge-Ring, (e) Local, (f) Near-full, (g) Normal, (h) Random and (i) Scratch .

Figure 3 shows an example visualization of the public drug tablet dataset used in this study. The training and validation accuracy curves and loss curves of the proposed model are shown in Figure 4. It is clear that the model successfully completed the training and did not experience overfitting. The ROC curve

presented in Figure 5 supports this. In the confusion matrix in Figure 6, only 6 test samples were mislabeled, while all other classes were correctly labeled. The t-SNE visualization space presented in Figure 7 shows how well the model differentiated and grouped the sample test images.

Table 3. Class-wise performance analysisof the proposed model

Classes	Precision	Recall	F1-Score
Center	1.000	1.000	1.000
Donut	1.000	1.000	1.000
Edge-Loc	1.000	0.987	0.994
Edge-Ring	0.987	1.000	0.994
Local	1.000	0.974	0.987
Near-full	0.962	0.974	0.968
Normal	1.000	1.000	1.000
Random	0.974	0.962	0.968
Scratch	0.975	1.000	0.987

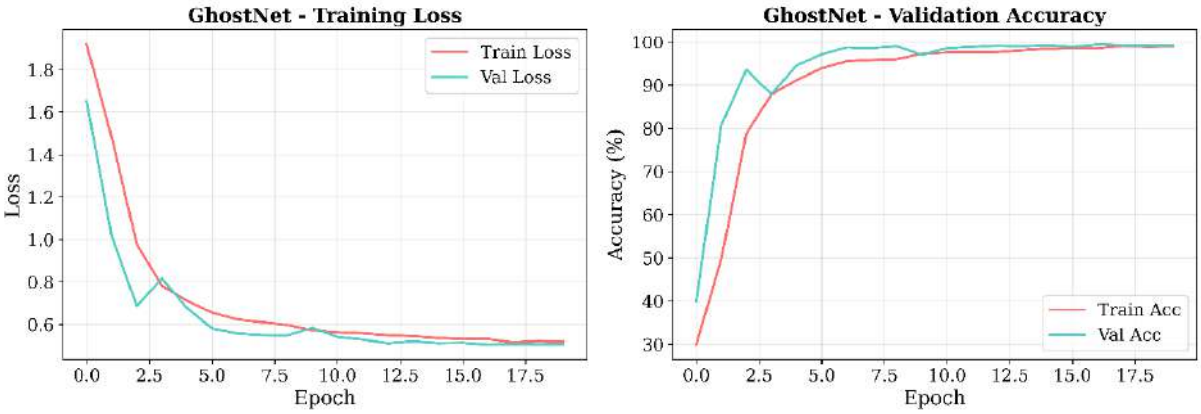

Figure 4. Training and validation curve of the proposed model

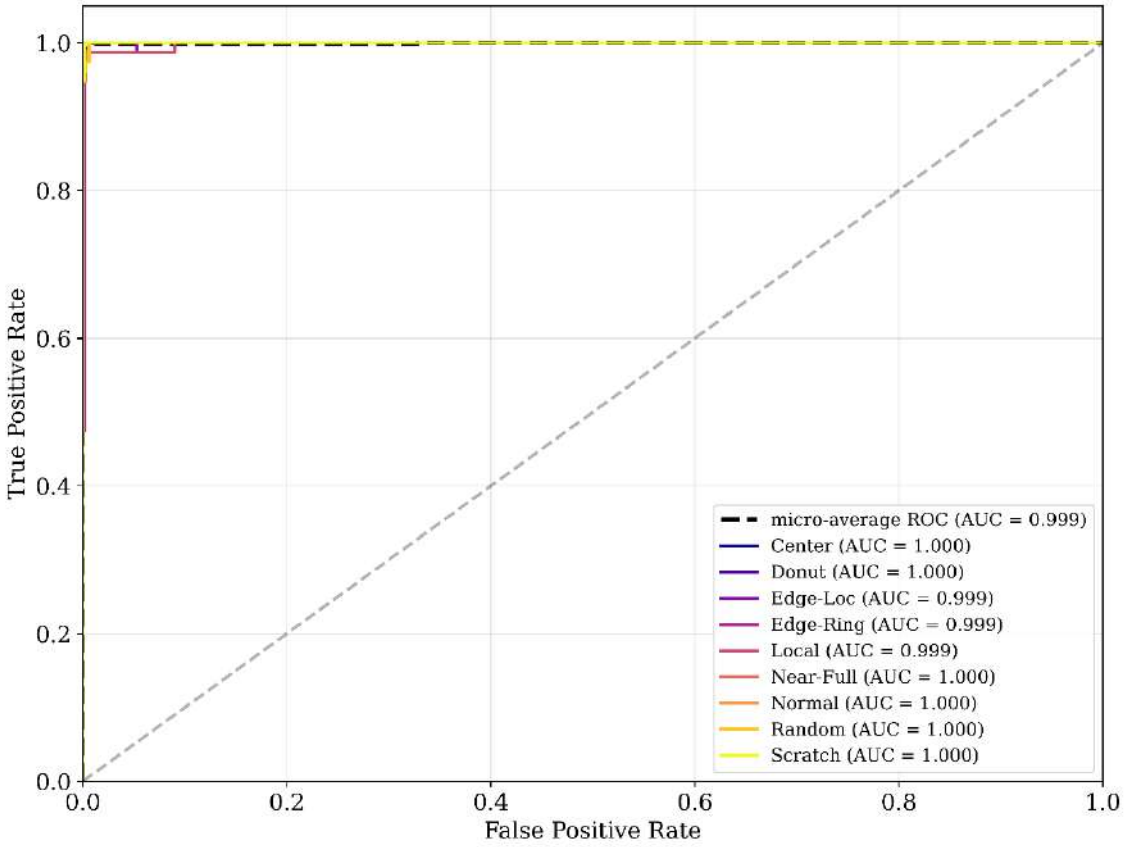

Figure 5. ROC curve of the proposed model

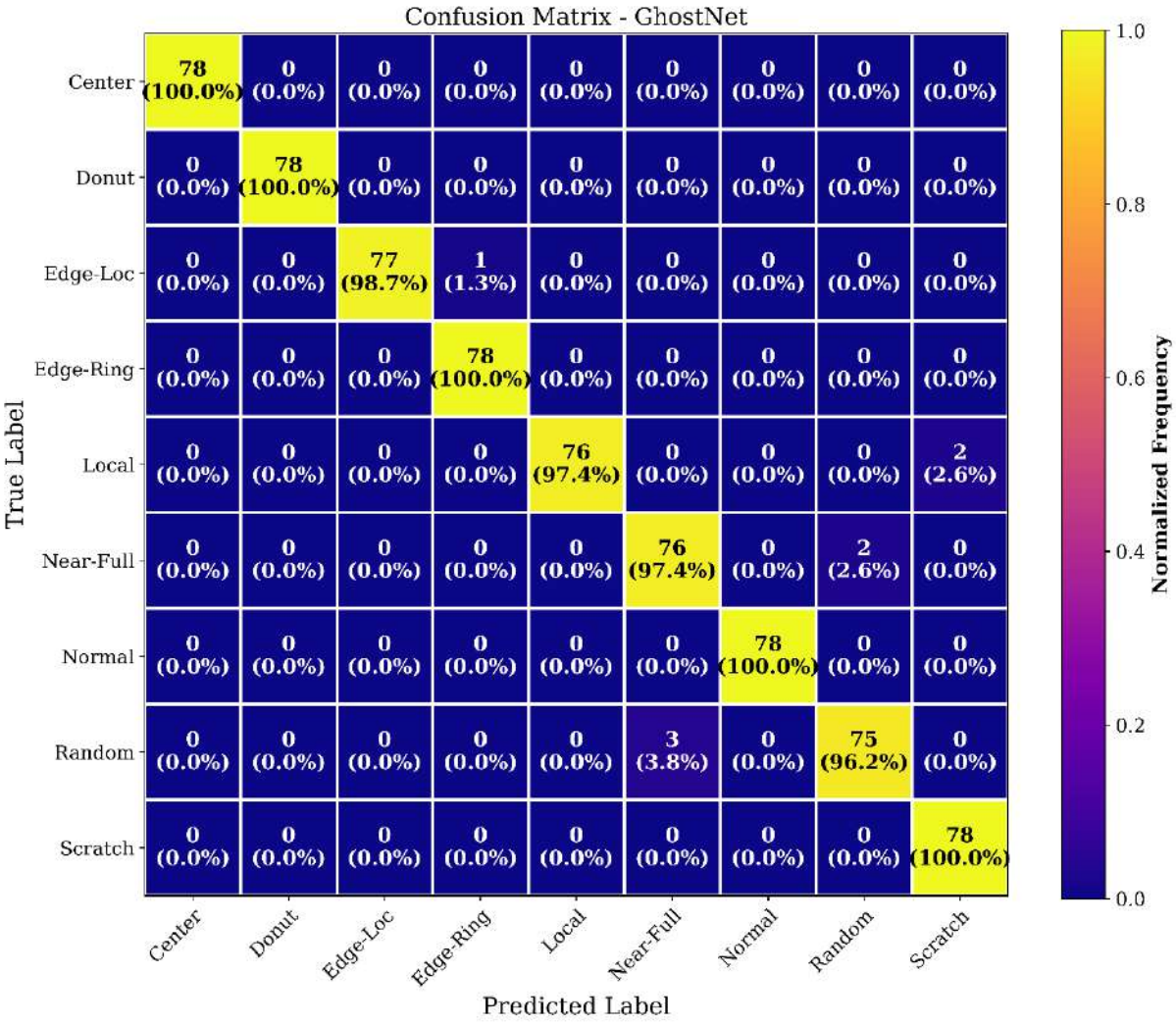

Figure 6. Confusion matrix of the proposed model

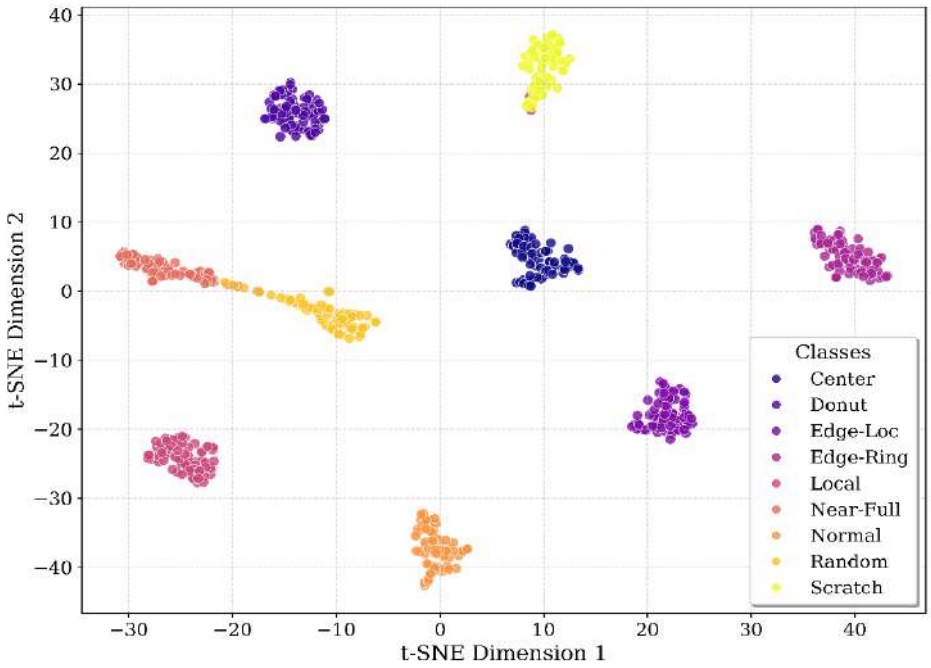

Figure 7. t-SNE visualization of the proposed model

CONCLUSIONS

In this study, a lightweight GhostNet-based model was developed for automatic classification of nine wafer defect patterns: Center, Donut, Edge-Loc, Edge-Ring, Local, Near-Full, Normal, Random, and Scratch. Using 5,616 wafer images, the proposed model achieved 98.97% training accuracy and 99.29% validation accuracy, demonstrating strong classification capability. The model required only 158,330 parameters, 0.60 MB of storage, and 23.546M FLOPs (0.024 GFLOPs), substantially reducing the computational cost compared with EfficientNetB0, MobileNetV2, and ResNet18. The Ghost Module, depthwise convolution, and Squeeze-and-Excitation mechanism contributed to this compact and efficient architecture. Confusion matrix, ROC, and t-SNE analyses further supported the model's effective class discrimination. Overall, the proposed GhostNet provides a strong balance between accuracy and computational efficiency, making it suitable for lightweight and potentially real-time wafer defect inspection. Future work will focus on larger datasets, different manufacturing conditions, and real-time industrial deployment.

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AUTOMATED NAIL DISEASE CLASSIFICATION USING DEiT-TINY

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ABSTRACT

Various dermatological disorders manifest as changes in the shape and structure of the nails. Accurate diagnosis of these disorders by a specialist is influenced by the physician's experience and prior knowledge of similar conditions. The advancement of this process using artificial intelligence has become increasingly popular recently. In this study, six different types of disorders were automatically identified using a lightweight transformer architecture, DeiT Tiny Transformer. Various data enhancement techniques were applied to the model during training to improve its generalization capabilities under different lighting conditions. Experimental results showed that the proposed model completed the diagnosis of nail diseases with 99.50% training accuracy and 97.15% validation accuracy. The proposed model learns data from its existing version with high performance and has a strong generalization ability on data it has not previously encountered. Furthermore, in this study, in addition to classification, the model's focus on diseased nails was visualized using Transformer-CAM, ROC curve, and confusion matrix results.

Keywords: Nail diseases, deep learning, Vision Transformer, DeiT-Tiny, image classification, explainable artificial intelligence, Transformer-CAM.

INTRODUCTION

Nails are an important anatomical structure that holds clues about the health of the human body. Various deformities on the nail surface can be considered indicative of both dermatological disorders and systemic diseases. Therefore, early detection of certain changes on the nail surface is very useful in determining which disease they belong to. The similarity of changes on the nail surface in the early stages of the disease and the dependence on physician experience create uncertainty. Traditional disease assessments rely on physician experience, laboratory tests, and physical examinations. The high patient load and limited number of specialists make the diagnostic process difficult. The visual similarity of some nail diseases makes diagnosis quite challenging. Indeed, different diagnoses can be made by different specialists and in different hospitals. Considering these reasons, the development of an automated image-based diagnostic system kit is beneficial. At this stage, various AI-supported diagnostic systems have been created with the aim of providing decision support and assisting in the pre-evaluation phases, rather than replacing the physician.

In recent years, convolutional neural network (CNN) based approaches have been used in the automated analysis of medical images. With the help of CNN, edge shapes and texture patterns in images have been examined in detail, producing successful results in medical image classification. However, due to the high computational capacity and high memory requirements of CNN-based approaches, alternative methods have also been developed. One of these is the Vision Transformer architecture. In addition, since the computational capacity of the classic Vision Transformer architecture remains high for some applications, the Data Efficient Image Transformer (De-IT) has emerged to lighten this architecture. In this study, this model was preferred due to its computational efficiency and lightweight structure. Many nail disease detection approaches exist in the literature.

Indi and Patil (2019) applied various processes such as pre-processing and segmentation to nail images. Color, shape, and texture features were extracted to determine the disease. After obtaining features such as standard deviation, skewness, and kurtosis, and generating values such as entropy and energy, classification was performed using various machine learning techniques such as Support Vector

Machine, k-Neighbour Nearest, and Random Forest. Abdulhadi et al. (2021) classified four different nail disease conditions: nail hyperpigmentation, normal nails, nail clubbing, and nail fungus, using transfer learning models. Using AlexNet, VGG16, GoogLeNet, ResNet50, and DenseNet201 architectures, the lowest result was obtained with the VGG16 model at 87.50% accuracy, while the highest result was achieved with ResNet50 and DenseNet201 at 96.39% accuracy.

Aishwarya and Nijhawan (2019) used the VGG19 transfer learning model for the automatic detection and classification of onychomycosis, a common nail disorder. Various machine learning architectures such as Decision Tree, Random Forest, and AdaBoost were tested to compare the classification performance. However, the highest results in onychomycosis detection were obtained with a deep learning-based architecture. Alzahrani et al. (2023) in their study... The dataset, which includes 821 nail images, contains diagnoses of eczema, normal nails, Beau's lines, and melanoma. Feature extraction was performed using VGG16, InceptionV3, and DenseNet201 transfer learning architectures. Stochastic Gradient Descent was then used in the classification phase. The highest result was obtained with DenseNet201 + SGDClassifier, achieving 94% accuracy.

Nijhawan et al. (2017) trained a CNN network from scratch on 11 different nail diseases: onychomycosis, subungual hematoma, Beau's lines, yellow nail syndrome, psoriasis, hyperpigmentation, koilonychia, paronychia, pincer nail, leukonychia, and onychorexis. The samples in the dataset were trained. This study was tested and trained using several different scenarios. In the first scenario, all nail images were trained from scratch on the CNN network. In the second scenario, the nail... The image was divided into upper and lower halves, and two different features were extracted using CNN and then classified using Random Forest during the classification phase. In the third scenario, CNN features from the upper, lower, and full nail images were combined, and the image was classified using Random Forest. In the final scenario, features were extracted from the upper-left, upper-right, lower-left, and lower-right images using CNN, and then the classification phase was again carried out using Random Forest. While an accuracy of 84.58% was obtained in Scenario 3, approximately the same accuracy was achieved in Scenario 4, although the training time for the model was approximately 4 hours longer.

Singhe et al. (2025) designed a hybrid model based on deep learning and machine learning for the automatic diagnosis of various nail infections and disorders. Acral Lentiginous Melanoma, healthy nail, onychogyrphosphatase Yamaç et al. (2022) established a hybrid architecture using the VGG16 model and SVM for 6 different nail diseases: Onychogryphosis, Blue Finger, Clubbing, and Pitting. The experimental performance yielded a total of 3835 images with 94.36% accuracy. They classified 5 different nail disorders: Blue Nail, Clubbing, Muehrcke's Lines, Splinter Hemorrhage, and Onycholysis. Using data augmentation techniques, they generated 1309 total images from a public nail disorder dataset containing 234 original images. VGG16, DenseNet169, MobileNet, Xception, InceptionResNetV2, and ResNet101V2 were used in this transfer learning model. Through testing, they achieved the highest accuracy of 89% with the ResNet101V2 architecture.

Nijhawan et al. (2026) used a Stable Diffusion-based text-to-image model for binary classification to classify diseases in visually diverse nail images. They applied few-shot learning to a specific nail dataset, using MobileNetV2 and Vision Transformer together. The acuradcy increase was 3.26% compared to using only MobileNetV2. Marulkar and Narain (2023) used CNN and Random Forest together to classify 11 different nail diseases—Beau lines, hyperpigmentation, onychomycosis, subungual hematoma, yellow nail syndrome, psoriasis, koilonychia, paronychia, pincer nails, leukonychia, and onychorexis—with 87.33% accuracy.

Chuanchit et al. (2023) Six different classes were found, and an accuracy of 84.6% was obtained with the DenseNet121 architecture on a dataset containing Beau's lines, Melanonychia, Nail Clubbing, Onycholysis, Terry's nail, and normal nails. The dataset used contained a total of 756 nail images, and its use in training was divided into 76% training, 14% validation, and 10% testing. Nasra and Gupta (2025) performed classification on a dataset containing six different nail diseases: Acral Lentiginous Melanoma, Healthy Nail, Onychogryphosis, Blue Finger, Clubbing, and Pitting, using the ResNet18 architecture. As a result of this approach, which involved the application of various data enhancement techniques, they achieved approximately 91% accuracy. Kaushik and Sharma (2024), in their study on

6 different nail diseases with a total of 3,835 nail images from the same dataset, achieved 89% accuracy with the DenseNet121 architecture.

Dora et al. (2025) completed the training of models with the ResNet101, VGG16, and InceptionV3 architectures using a transfer learning approach on a public nail disease dataset. With a total of 8536 nail images from a dataset of 17 different nail diseases, they achieved 99.94% accuracy in the ResNet101 architecture. Hadiyoso and Aulia (2022), using the VGG16 architecture, Adam optimizer, and 10 epoch training, achieved 96% accuracy for 3 different nail disease classes: Koilonychia, Beau's Lines, and Leukonychia. Rajan et al. (2022) similarly achieved 95% accuracy using the AlexNet transformer learning architecture with a total of 185 nail images. In this study, unlike other studies, classification was done binary (healthy-diseased) instead of multi-class disease classification. Boopathi et al. (2025) obtained 97% accuracy by applying fine-tuning to the MobileNetV2 architecture with 10 different diseases including Acral Lentiginous Melanoma, Healthy Nail, Onychogryphosis, Bluish Nail, Clubbing, Onychomycosis, Pitting, Psoriasis, Splinter Hemorrhage and Yellow Nail, containing a total of 5,730 labeled nail images from a public nail database.

Table 1. Literature review for nail disease classification

Study	Method	Dataset	Accuracy
Abdulhadi et al. (2021)	AlexNet, VGG16, GoogleNet, ResNet50, DenseNet201	280 images, 4 classes	96.39%
Alzahrani et al. (2023)	VGG16, InceptionV3, DenseNet201 + SGD	821 images, 4 classes	94.00%
Nijhawan et al. (2017)	Hybrid CNN + Random Forest	11 classes	84.58%
Singhe et al. (2025)	VGG16 + SVM	6 classes	94.36%
Yamaç et al. (2022)	VGG16, DenseNet169, MobileNet, Xception, InceptionResNetV2, ResNet101V2	234 images → 1,309 augmented images, 5 classes	89.00%
Marulkar and Narain (2023)	CNN + Random Forest	11 classes	87.33%
Chuanchit et al. (2023)	DenseNet121 + Transfer Learning	756 images, 6 classes	84.60%
Nasra and Gupta (2025)	ResNet18 + Data Augmentation	6 classes	>91.00%
Kaushik and Sharma (2024)	DenseNet121 + Transfer Learning	3,835 images, 6 classes	89.00%
Dora et al. (2025)	ResNet101, VGG16, InceptionV3 + Transfer Learning	8,536 images, 17 classes	99.94%
Hadiyoso and Aulia (2022)	VGG16 + Adam Optimizer + Transfer Learning	3 classes	96.00%
Rajan et al. (2022)	AlexNet + Transfer Learning	185 images, binary classification	95.00%
Boopathi et al. (2025)	MobileNetV2 + Fine-tuning	5,730 images, 10 classes	99.69%

METHODOLOGY

A lightweight vision transformer model was used to automatically identify which disease symptom is present in nail images. Morphological features were automatically extracted from color, texture, and shape characteristics of nail images using a highly accurate and lightweight model. In the first stage, the images in the dataset were automatically scanned according to class folders, and each image was matched with a label belonging to the relevant disease class. The dataset used was a public dataset obtained from Kaggle (Gurov, 2024), with data separated as 70% training, 15% validation, and 15% test. Figure 2 shows which diseases nail disorders might be indicative of. Various data augmentation techniques were also applied to this dataset, which consisted of 224x224 pixel nail images taken under different lighting conditions. DeiT-Tiny is a lightweight Vision Transformer architecture that divides images into small 16x16 pixel image patches and processes these patches as Transformer tokens. A 224x224 input image is divided into 196 image patches and transferred to Transformer layers along with a custom token used for classification. Thanks to its self-attention mechanism, the model can learn the relationships between different regions of the nail image and evaluate distinctive visual patterns related to the disease within a global context. The model's original classification layer was restructured according to the six-class problem in the study, and the output size was set to six.

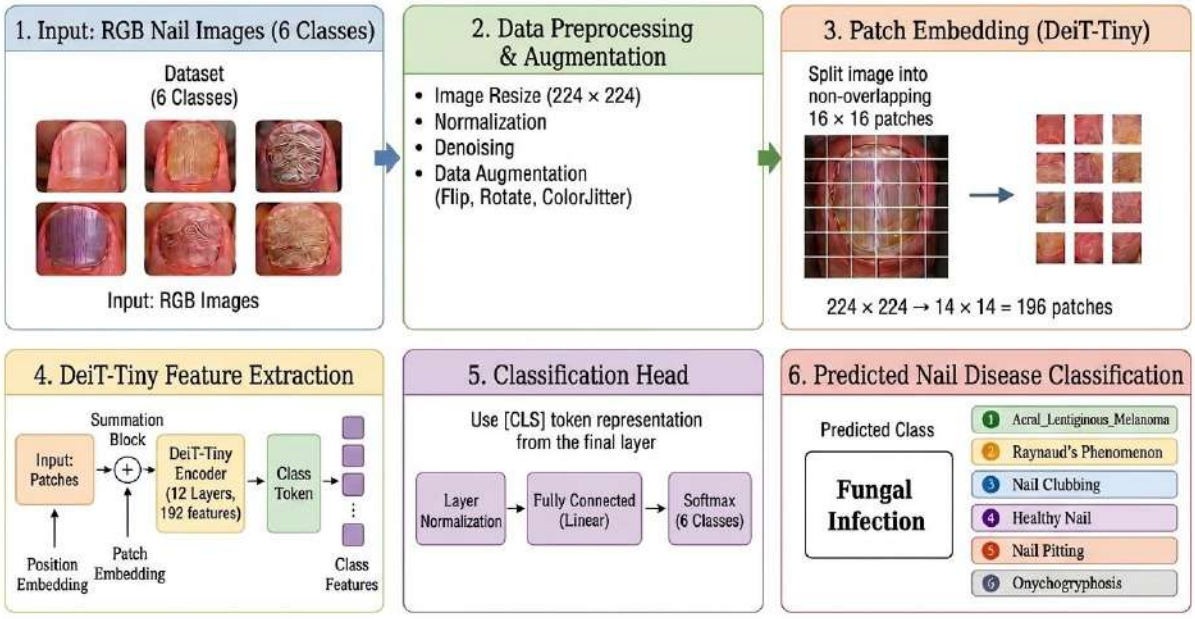


Figure 1. Nail disease detection for proposed arcitecture

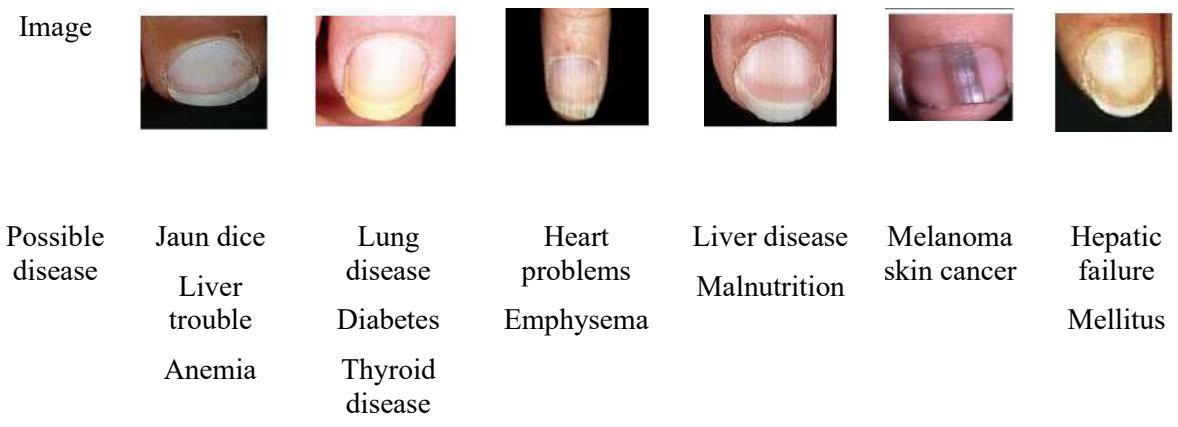
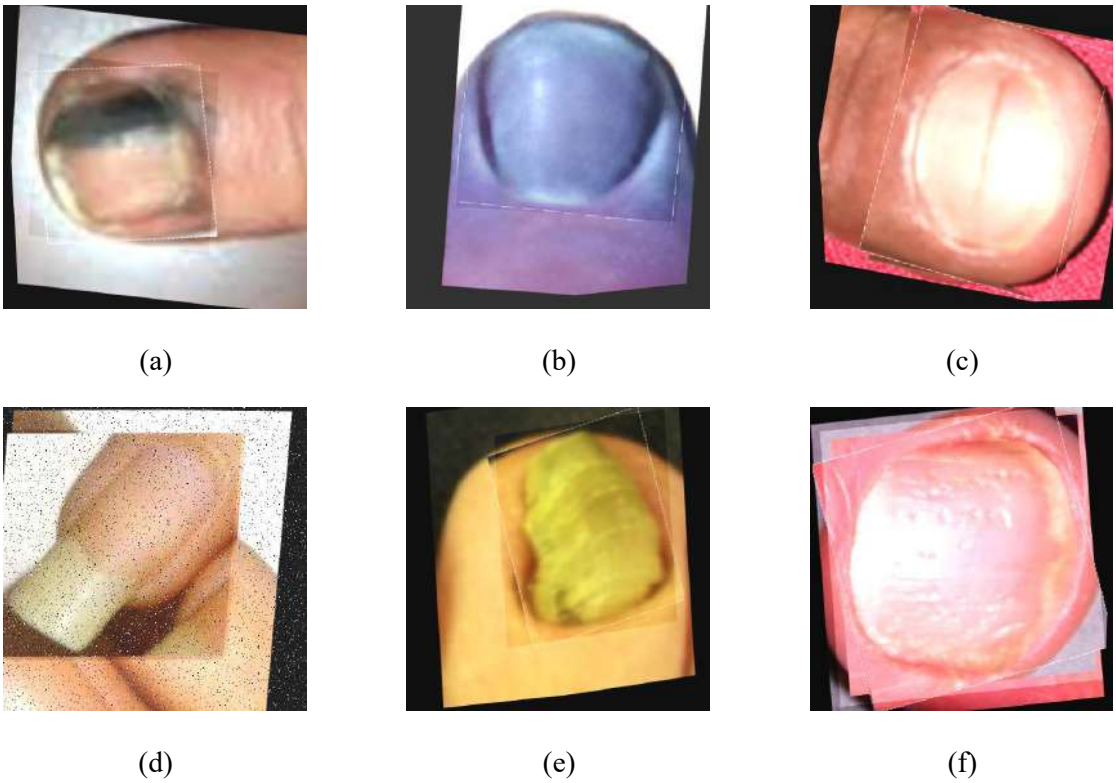


Figure 2. Nail diseases based on color and shape

EXPERIMENTAL RESULTS

In this study, classification metrics, complexity matrix, ROC curve, and classification score for each class were evaluated to assess the performance of the proposed model. This study was conducted on a system with a 13th generation Intel Core i7-13620H central processing unit (CPU) and an NVIDIA GeForce RTX 4060 Laptop GPU graphics processing unit (GPU). Figure 3 shows an example visualization of the public nail disease dataset used in this study. The training and validation accuracy curves and loss curves of the proposed model are shown in Figure 4. It is clear that the model successfully completed the training and did not experience overfitting. The ROC curve presented in Figure 5 supports this. In the confusion matrix in Figure 6, only 16 test samples were mislabeled, while all other classes were correctly labeled. The t-SNE visualization space presented in Figure 7 shows how well the model differentiated and grouped the sample test images.



(a) (b) (c)

(d) (e) (f)

Figure 3. Sample drug images belonging to the categories (a) Acral_Lentiginous_Melanoma, (b) blue_finger, (c) clubbing, (d) Healthy_Nail, (e) Onychogryphosis, (f) pitting .

Table 3. Class-wise performance analysisof the proposed model

Classes	Precision	Recall	F1-Score	Support
Acral_Lentiginous_Melanoma	0.9908	0.9730	0.9818	111
Healthy_Nail	1.0000	0.9583	0.9887	48
Onychogryphosis	1.0000	0.9804	0.9901	102
Blue_finger	0.9556	0.9556	0.9556	90
Clubbing	0.9262	0.9826	0.9536	115
Pitting	0.9789	0.9688	0.9738	96

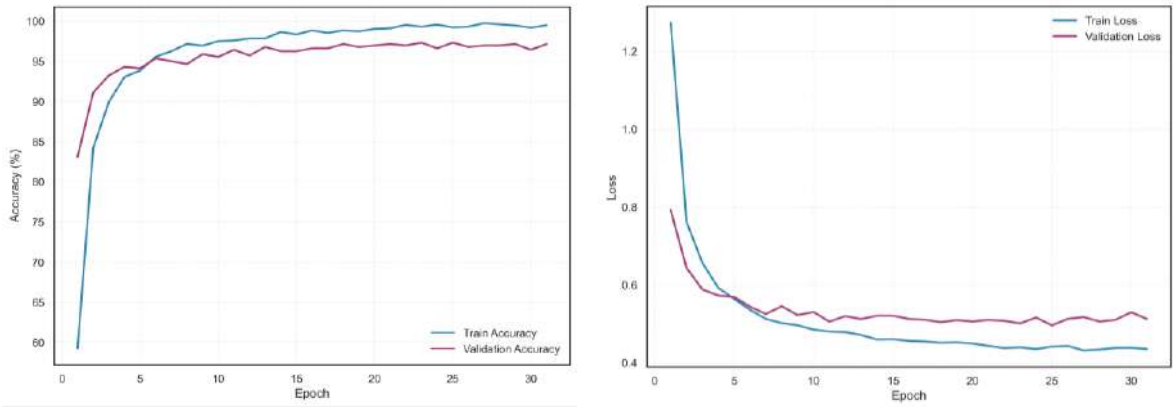


Figure 4. Training and validation curve of the proposed model

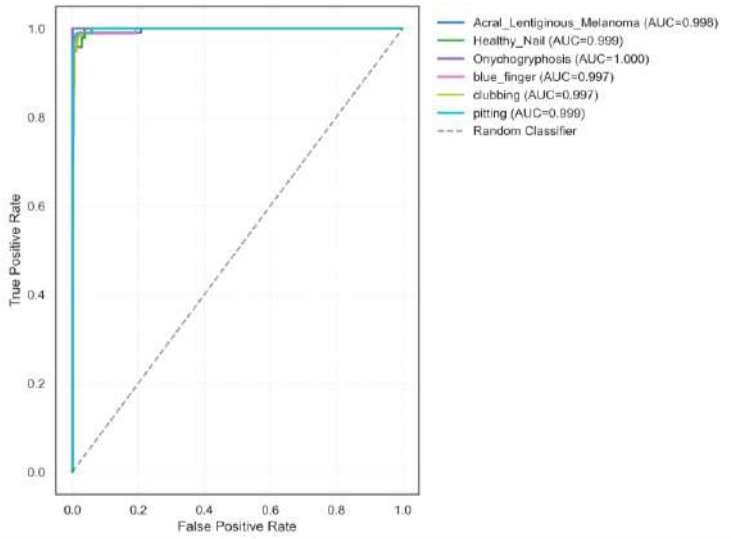


Figure 5. ROC curve of the proposed model

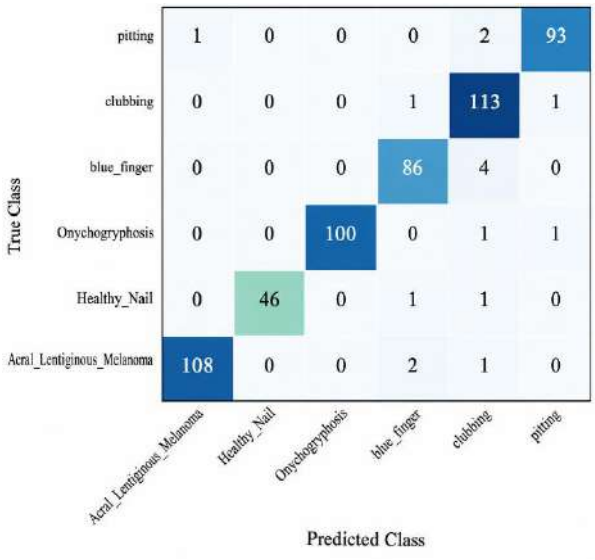


Figure 6. Confusion matrix of the proposed model

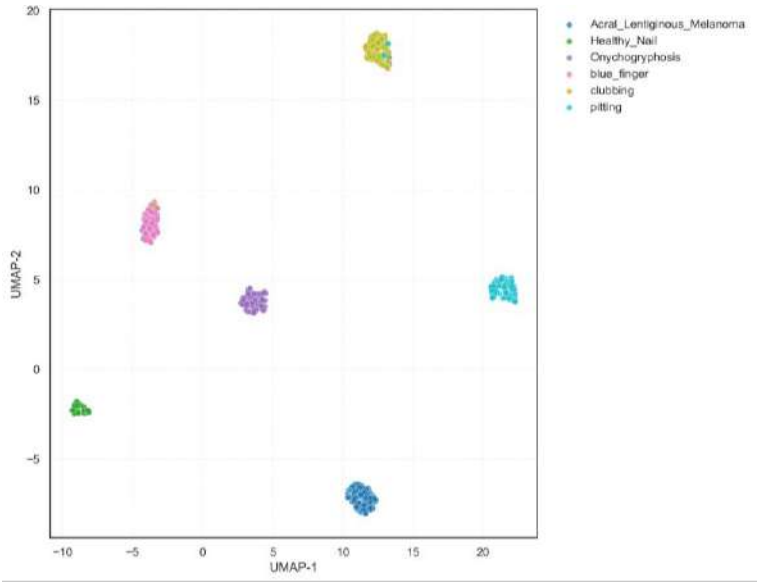
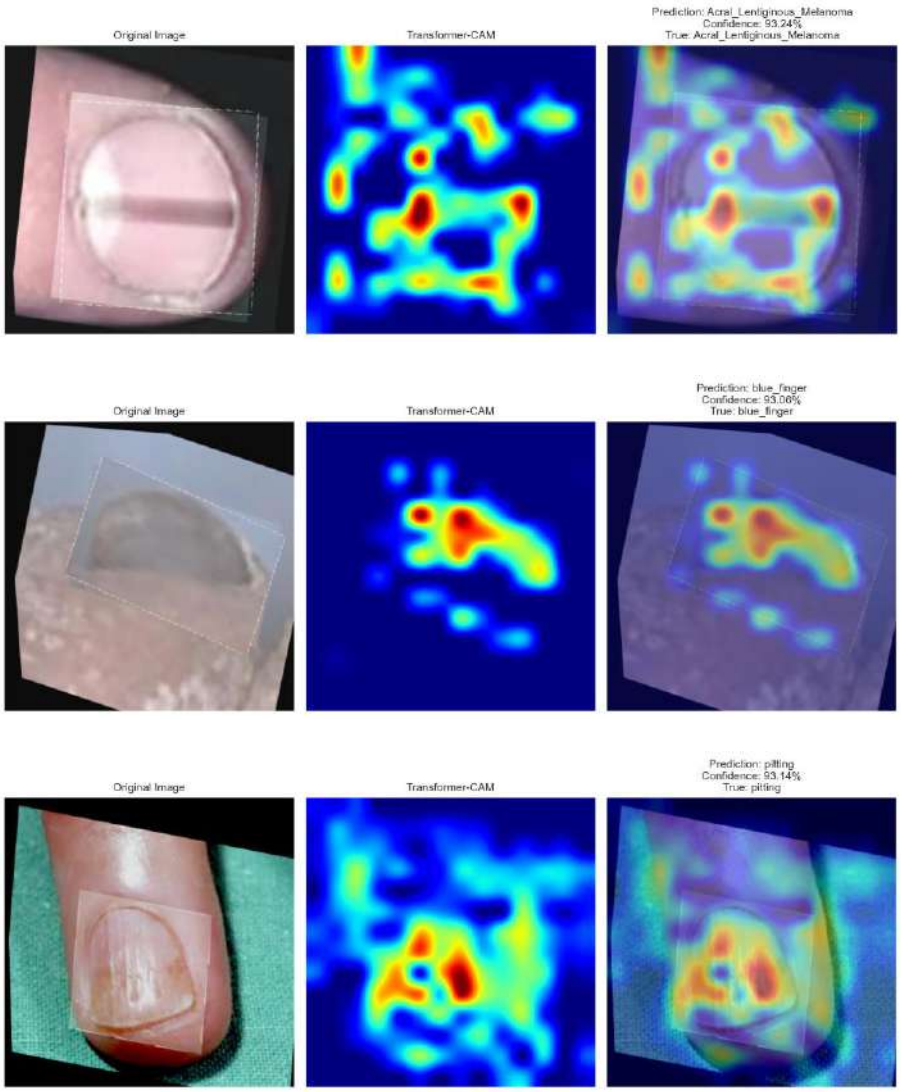


Figure 7. t-SNE visualization of the proposed model



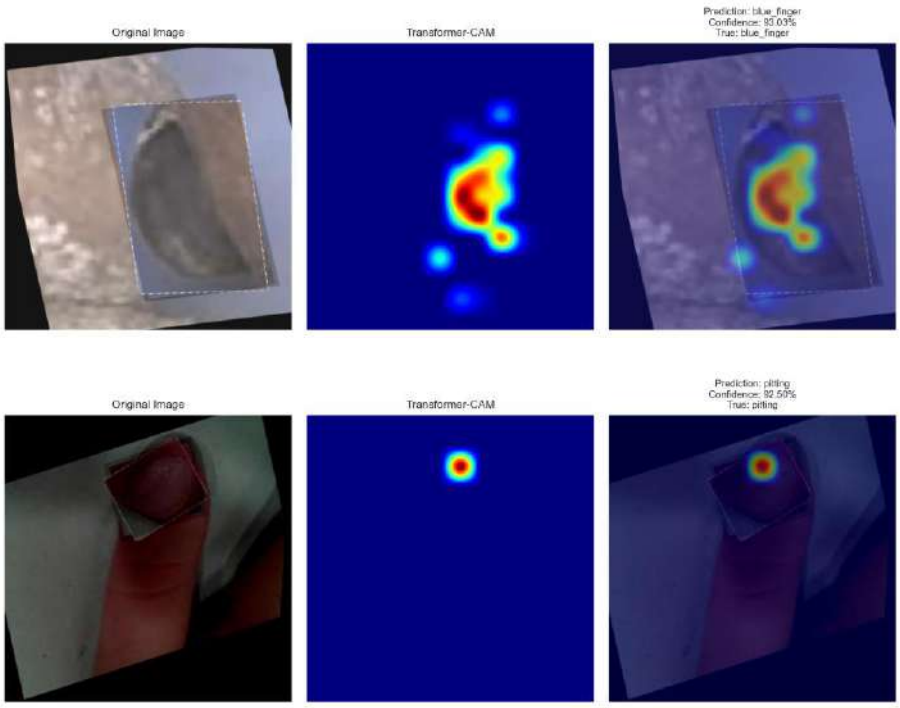


Figure 8. Transformer-CAM visualization of the proposed model

CONCLUSIONS

In this study, a lightweight DeiT-Tiny-based Vision Transformer model was developed for the automatic classification of six nail disease classes. Using ImageNet-pretrained weights and data augmentation, the proposed model achieved 99.50% training accuracy and 97.15% validation accuracy. The Transformer-based architecture enables effective learning of discriminative visual patterns from nail images while maintaining a lightweight structure. Model performance was evaluated using accuracy, precision, recall, F1-score, and confusion matrix analysis. In addition, Transformer-CAM was employed to visualize the image regions contributing to the model's predictions, improving the interpretability of the classification process. The results demonstrate that the proposed approach provides a promising balance between classification performance and interpretability for AI-assisted nail disease screening. Future work will focus on larger clinical datasets, external validation, and real-world smartphone-based applications.

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BOŞ ZAMANIN GÜVENCESİZLEŞMESİ: PREKARYA, ZAMANSAL EŞİTSİZLİK VE REKREASYON ÜZERİNE BİR DERLEME

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ÖZET

Günümüz çalışma yaşamında esnekleşme, geçici istihdam, düzensiz çalışma süreleri, eksik istihdam ve gelir belirsizliğinin yaygınlaşması, güvencesizliği yalnızca istihdam alanına özgü bir sorun olmaktan çıkararak bireylerin gündelik yaşam pratiklerini ve çalışma dışı zamanlarını etkileyen çok boyutlu bir olgu hâline getirmiştir. Bu dönüşümü açıklamada kullanılan prekarya kavramı; istihdam ve gelir güvencesizliğinin yanı sıra mesleki geleceğin öngörülemezliği, zaman üzerindeki kontrolün zayıflaması ve çalışma ile çalışma dışı yaşam arasındaki sınırların belirsizleşmesiyle karakterize edilen bir yaşam deneyimine işaret etmektedir. Türkiye işgücü piyasasına ilişkin güncel göstergeler de bu tartışmanın önemini ortaya koymaktadır. Türkiye İstatistik Kurumu verilerine göre 2025 yılında işsizlik oranı %8,3 olarak gerçekleşirken, zamana bağlı eksik istihdam, potansiyel işgücü ve işsizlerden oluşan atıl işgücü oranı %29,7'ye ulaşmıştır. Aynı dönemde zamana bağlı eksik istihdam ile işsizliğin bütünleşik oranı %19,6 olarak gerçekleşmiştir. Bu derlemenin amacı, prekaryalaşma ile rekreasyon arasındaki ilişkiyi mevcut kuramsal ve ampirik literatür ile güncel işgücü göstergeleri doğrultusunda incelemek ve güvencesiz çalışma koşullarının bireylerin boş zaman deneyimleri ve rekreasyonel katılımları üzerindeki olası yansımalarını tartışmaktır. Bu doğrultuda prekarya ve rekreasyon ilişkisi ekonomik güvencesizlik, zamansal güvencesizlik, zaman üzerinde kontrol, zaman yoksulluğu, boş zamanın parçalanması ve rekreasyonel eşitsizlik eksenlerinde ele alınmıştır. Literatür, çalışma dışı zamanın varlığının tek başına nitelikli ve özerk bir boş zaman deneyimini garanti etmediğine; zamanın öngörülebilirliği, sürekliliği ve bireyin bu zaman üzerindeki kontrolünün rekreasyonel deneyimin niteliği açısından belirleyici olabileceğine işaret etmektedir. Bu çerçevede derlemede, prekaryalaşmanın ekonomik ve zamansal güvencesizlik aracılığıyla bireyin zamanı üzerindeki özerkliğini azaltabileceği, boş zamanı parçalı ve öngörülemez hâle getirebileceği ve sonuç olarak rekreasyona erişim ile rekreasyonel deneyimin niteliğinde eşitsizlikler üretebileceği ileri sürülmektedir. Sonuç olarak rekreasyonel katılımın yalnızca bireysel tercih, motivasyon ve boş zaman miktarı üzerinden değil; istihdam koşulları, ekonomik kaynaklar, zaman üzerinde kontrol ve yapısal eşitsizlikler bağlamında değerlendirilmesi gerektiği düşünülmektedir. "Boş zamanın güvencesizleşmesi" yaklaşımının, prekarya ile rekreasyon arasındaki ilişkinin kavramsallaştırılmasına ve rekreasyonel eşitsizlikleri konu alan gelecekteki araştırmalara kuramsal bir zemin sağlayabileceği öngörülmektedir.

Anahtar Kelimeler: Prekarya, rekreasyon, boş zaman, güvencesiz çalışma, zaman yoksulluğu, rekreasyonel eşitsizlik.

GİRİŞ

Çalışma yaşamında son yıllarda belirginleşen esnekleşme, geçici istihdam, düzensiz çalışma süreleri, platform temelli çalışma ve gelir belirsizliği gibi dönüşümler, güvencesizliği yalnızca istihdam alanına özgü bir sorun olmaktan çıkararak gündelik yaşamın farklı boyutlarını etkileyen çok katmanlı bir olgu hâline getirmiştir. Standart istihdam ilişkisinin süreklilik, öngörülebilirlik ve belirli çalışma saatleri üzerine kurulu yapısının zayıflaması; bireyin yalnızca gelir ve mesleki geleceğine ilişkin güvenini değil, gündelik yaşamını ve zamanını planlama kapasitesini de etkileyebilmektedir. Bu nedenle çağdaş çalışma yaşamındaki güvencesizliğin sonuçlarını yalnızca istihdam ve gelir üzerinden değerlendirmek, bireyin çalışma dışındaki yaşamında ortaya çıkan dönüşümleri açıklamak açısından yetersiz kalabilmektedir.

Bu dönüşümü açıklamak amacıyla kullanılan kavramlardan biri "prekarya"dır. Standing (2011), prekaryayı istikrarlı bir mesleki kimlikten, güvenli istihdam ilişkilerinden ve geleceğe ilişkin

öngörülebilirlikten yoksun bir toplumsal konumla ilişkilendirmektedir. Bununla birlikte prekaryanın ayrı bir sınıf oluşturduğu yönündeki yaklaşım literatürde tartışmalıdır. Türkiye bağlamında Oğuz (2011), güvencesizleşmenin yeni bir sınıfın ortaya çıkışından çok kapitalist emek ilişkilerindeki dönüşümler bağlamında değerlendirilmesi gerektiğine dikkat çekmektedir. Bu nedenle prekarya, yalnızca belirli bir çalışan grubunu tanımlayan kategorik bir kavram olarak değil; istihdam, gelir, mesleki gelecek ve gündelik yaşam üzerinde süreklilik gösteren bir güvencesizleşme deneyimini anlamaya imkân sağlayan analitik bir çerçeve olarak değerlendirilebilir.

Prekaryalaşmanın rekreasyon açısından önem taşıyan yönlerinden biri, güvencesizliğin zamansal boyutudur. Güvencesiz istihdam koşullarında bireyin sorunu yalnızca ne kadar gelir elde ettiği veya kaç saat çalıştığı değildir. Ne zaman çalışacağını önceden bilmemesi, çalışma programı üzerinde sınırlı kontrol sahibi olması, işe çağrılmayı beklemesi veya çalışma saatlerinin kısa süre içerisinde değişebilmesi de bireyin çalışma dışı yaşamını doğrudan etkileyebilmektedir. Schneider ve Harknett (2019), çalışma programlarındaki istikrarsızlığın güvencesizliğin önemli ancak görece ihmal edilmiş zamansal boyutlarından biri olduğunu belirtmektedir. Benzer biçimde Henly ve Lambert (2014), çalışma zamanının öngörülemezliğinin iş-yaşam çatışması ve algılanan stres ile ilişkili olduğunu göstermiştir.

Bu durum boş zaman ve rekreasyon kavramlarının prekarya perspektifinden yeniden değerlendirilmesini gerekli kılmaktadır. Rekreasyon literatüründe boş zaman çoğunlukla çalışma ve zorunlu yaşam etkinlikleri dışında kalan ve bireyin görece özgür seçimlerde bulunabildiği bir yaşam alanı olarak değerlendirilmektedir. Ancak çalışma dışı zamanın varlığı, söz konusu zamanın bireyin kontrolünde olduğunu veya rekreasyonel amaçlarla özgürce kullanılabileceğini tek başına göstermemektedir. Bireyin çalışmadığı hâlde işe çağrılma olasılığını beklemesi, yeni iş fırsatları araması, ek gelir elde etmek amacıyla ikinci bir işe yönelmesi veya bir sonraki çalışma programını öngörememesi durumunda, çalışma dışı zaman niceliksel olarak mevcut olsa bile niteliksel olarak özerk bir boş zaman niteliği taşımayabilir.

Batchelor, Fraser, Whittaker ve Li (2020), bu durumu "precarious leisure" kavramı üzerinden ele alarak işgücü piyasasındaki güvencesizliğin çalışma alanının dışına taşarak gençlerin boş zaman deneyimlerini de etkileyebildiğini ortaya koymaktadır. Bu yaklaşım, boş zamanın yalnızca miktarına değil; öngörülebilirliğine, sürekliliğine, niteliğine ve bireyin bu zaman üzerindeki kontrolüne odaklanılması gerektiğini düşündürmektedir.

Türkiye'de çalışma zamanı ve boş zaman ilişkisini ele alan çalışmalar da benzer bir sorunsala işaret etmektedir. Sarıipek (2016), çalışma yaşamındaki zaman baskısının boş zaman algısına yansımalarını tartışırken modern çalışma düzeninin bireyin çalışma dışındaki zamanını da biçimlendirdiğine dikkat çekmektedir. Öneş, Memiş ve Kızılırmak (2013) ise Türkiye'de zaman yoksulluğunun gelir yoksulluğundan bağımsız düşünülemeyecek önemli bir dezavantaj alanı olduğunu göstermektedir. Bu sonuçlar, rekreasyona erişimde yalnızca ekonomik kaynakların değil, bireyin kullanabileceği zamanın miktarı ve niteliğinin de bir eşitsizlik kaynağı olabileceğine işaret etmektedir.

Türkiye işgücü piyasasının güncel görünümü de bu tartışmanın önemini güçlendirmektedir. Türkiye İstatistik Kurumu verilerine göre 2025 yılında işsizlik oranı %8,3 olarak gerçekleşirken, zamana bağlı eksik istihdam, potansiyel işgücü ve işsizlerden oluşan atıl işgücü oranı %29,7'ye ulaşmıştır. Zamana bağlı eksik istihdam ile işsizliğin bütünleşik oranı ise %19,6 olarak gerçekleşmiştir. Ayrıca 2025 yılının son çeyreğinde istihdam edilenlerin haftalık ortalama fiili çalışma süresi 42,6 saat olmuştur. Bu göstergeler tek başına prekaryanın doğrudan ölçüsü olarak değerlendirilmemelidir; ancak işgücü piyasasındaki kırılganlık, eksik istihdam ve çalışma zamanı üzerindeki baskıların büyüklüğünü ortaya koymaları açısından önemlidir.

Rekreasyonel katılımın önündeki engeller açısından değerlendirildiğinde bu durum ayrıca önem kazanmaktadır. Crawford, Jackson ve Godbey'in (1991) hiyerarşik boş zaman kısıtları modeli, rekreasyonel katılımın bireysel tercihten ibaret olmadığını; içsel, kişilerarası ve yapısal kısıtların katılım üzerinde etkili olduğunu ortaya koymaktadır. Ekonomik kaynakların yetersizliği ve zaman eksikliği yapısal engeller içerisinde değerlendirilebilmektedir. Prekarya perspektifi ise bu tartışmaya farklı bir boyut eklemektedir: sorun yalnızca bireyin yeterli boş zamana sahip olmaması değil, sahip olduğu zaman üzerinde ne ölçüde kontrol kurabildiğidir.

Bu doğrultuda mevcut derlemenin amacı, prekaryalaşma ile rekreasyon arasındaki ilişkiyi kuramsal ve ampirik literatür çerçevesinde incelemek; güvencesiz çalışma koşullarının bireyin zaman üzerindeki kontrolü, boş zaman deneyimi ve rekreasyonel katılımı üzerindeki olası etkilerini tartışmaktır. Çalışmanın temel varsayımı, prekaryalaşmanın yalnızca çalışma yaşamını değil, bireyin çalışma dışı zamanı üzerindeki kontrolünü de etkileyerek "boş zamanın güvencesizleşmesine" neden olabileceğidir.

Prekarya Kavramı ve Kuramsal Temelleri

Prekarya kavramı, özellikle neoliberal ekonomik dönüşümlerin çalışma yaşamında yarattığı esneklik ve güvencesizlik biçimlerini açıklamak amacıyla sosyal bilimlerde giderek daha fazla kullanılmaktadır. Kavram özellikle Standing'in çalışmalarıyla yaygınlık kazanmıştır. Standing'e (2011) göre prekarya, geleneksel proletaryadan farklı olarak istikrarlı bir istihdam ilişkisine, belirgin bir mesleki kimliğe ve geleceğe yönelik güvenli bir kariyer beklentisine sahip olmayan bireylerden oluşmaktadır.

Bununla birlikte prekaryayı yalnızca belirli mesleklerde çalışan veya düşük gelir elde eden bireylerle sınırlandırmak kavramın açıklayıcı kapasitesini azaltabilir. Güvencesizlik düşük ücretin yanı sıra geçici çalışma, çalışma sürelerinin değişkenliği, sosyal koruma mekanizmalarının yetersizliği, kariyer olanaklarının belirsizliği ve çalışma zamanı üzerindeki kontrolün azalması gibi farklı biçimlerde ortaya çıkabilmektedir.

Türkiye literatüründe Oğuz (2011), güvencesiz çalışma ve yaşam koşullarını ele alarak prekarya kavramının proletaryadan tamamen bağımsız yeni bir toplumsal sınıfı temsil edip etmediğini sorgulamaktadır. Bu eleştirel yaklaşım, prekaryanın homojen ve sınırları kesin bir toplumsal kategori olarak kullanılmasından kaçınılması gerektiğini göstermektedir. Bu nedenle mevcut derlemede prekarya, sabit bir sınıfsal kategori olmaktan çok çalışma ve yaşam koşullarının güvencesizleşmesini açıklayan analitik bir perspektif olarak kullanılmaktadır.

Vatansever'in (2013) beyaz yakalı çalışanlar üzerinden yürüttüğü tartışma da güvencesizliğin yalnızca geleneksel olarak dezavantajlı kabul edilen emek gruplarıyla sınırlı olmadığını göstermesi açısından önemlidir. Yüksek eğitim düzeyine sahip bireylerin de kariyer belirsizliği, performans baskısı ve geleceğe ilişkin güvensizlik deneyimleriyle karşılaşabilmesi, prekaryalaşmanın toplumsal kapsamının genişlediğini göstermektedir.

Prekarya tartışmasının rekreasyon açısından temel önemi, güvencesizliğin çalışma ortamında başlayan ancak bireyin zamanı kullanma ve geleceği planlama biçimine de yayılan bir süreç olmasıdır. Geleneksel çalışma düzeninde çalışma zamanı ile çalışma dışı zaman arasında görece belirgin sınırlar bulunduğu varsayılabilirken, esnek ve dijital çalışma biçimleri bu sınırların giderek geçirgenleşmesine yol açmaktadır.

Bu bağlamda prekaryalaşmanın rekreasyon açısından üç temel boyutu öne çıkmaktadır. Birincisi ekonomik güvencesizliktir. Gelir düzeyinin düşük veya öngörülemez olması, ücretli rekreasyon faaliyetlerine erişimi sınırlandırabilir. İkincisi zamansal güvencesizliktir. Çalışma zamanının öngörülememesi ve bireyin çalışma programı üzerinde kontrolünün sınırlı olması rekreasyonel faaliyetlerin planlanmasını güçleştirebilir. Üçüncüsü geleceğe ilişkin belirsizliktir. Sürekli yeni iş aramak, istihdam edilebilirliği artırmaya çalışmak veya gelir kaybına karşı hazırlıklı olmak zorunda hisseden bireyin çalışma dışı zamanının psikolojik olarak çalışma yaşamından bağımsızlaşması zorlaşabilir.

Zamansal Güvencesizlik ve Boş Zamanın Dönüşümü

Zaman, rekreasyonun temel kaynaklarından biridir. Ancak rekreasyonel deneyimin oluşabilmesi açısından yalnızca zamanın niceliksel olarak mevcut olması yeterli değildir. Bireyin söz konusu zamanı nasıl kullanacağını belirleyebilmesi, zamanını önceden planlayabilmesi ve zorunluluklardan görece bağımsız biçimde değerlendirebilmesi de önemlidir.

Goodin ve arkadaşları (2008) "discretionary time" yaklaşımı, zamanı özgürlük ve özerklik bağlamında ele almakta ve bireyin zorunlu faaliyetler sonrasında gerçekten kontrol edebildiği zamana odaklanmaktadır. Bu perspektiften bakıldığında boş zamanın miktarı kadar zamansal özerklik de önemli hâle gelmektedir.

Prekarya koşullarında tam olarak bu zamansal özerklik zayıflayabilmektedir. Schneider ve Harknett (2019), çalışma programındaki istikrarsızlığın çalışanların iş-yaşam çatışması ve iyi oluşları üzerinde önemli sonuçlar yarattığını göstermektedir. Henly ve Lambert (2014) de öngörülemeyen çalışma zamanlarının iş-yaşam çatışmasıyla ilişkili olduğunu ortaya koymaktadır.

Bu bulgular rekreasyon açısından önemli bir ayrımı gerekli kılmaktadır:

Çalışma dışı zaman ≠ boş zaman ≠ rekreasyonel olarak özerk zaman.

Bir birey belirli bir gün çalışmıyor olabilir; ancak ertesi gün işe çağrılıp çağrılmayacağını bilmiyorsa bu zamanı seyahat, spor, kültürel etkinlik veya sosyal bir rekreasyon faaliyeti için önceden planlayamayabilir. Benzer biçimde gün içerisinde kısa ve birbirinden kopuk çalışma dışı zaman parçalarına sahip olmak ile kesintisiz ve önceden öngörülebilir bir boş zaman dilimine sahip olmak rekreasyon açısından aynı değeri taşımayabilir.

Bu durum boş zamanın parçalanması kavramıyla açıklanabilir. Rekreasyonel faaliyetlerin önemli bir bölümü yalnızca belirli bir zaman miktarını değil, zamanın sürekliliğini ve öngörülebilirliğini de gerektirir. Dolayısıyla prekaryalaşma toplam çalışma dışı zamanı mutlaka ortadan kaldırmasa bile bu zamanın rekreasyonel kullanılabilirliğini azaltabilir.

Batchelor ve arkadaşlarının (2020) “precarious leisure” yaklaşımı bu noktada önem kazanmaktadır. Araştırmacılar, gençlerin güvencesiz işgücü piyasası deneyimlerinin yalnızca çalışma yaşamlarını değil, boş zamanlarını ve zaman algılarını da etkileyebildiğini belirtmektedir. Böylece boş zamanın güvencesizleşmesi yalnızca boş zamanın azalması anlamına gelmemekte; zamanın belirsiz, parçalı ve gelecekteki çalışma taleplerine bağımlı hâle gelmesini de içermektedir.

Zaman Yoksulluğu ve Rekreasyonel Eşitsizlik

Rekreasyonel katılım bireysel tercihlerin sonucu olmakla birlikte, bu tercihlerin yapısal koşullardan bağımsız biçimde oluşmadığı açıktır. Ekonomik kaynaklar, kullanılabilir zaman, ulaşım olanakları ve sosyal çevre rekreasyonel katılım üzerinde belirleyici olabilmektedir.

Crawford, Jackson ve Godbey (1991) tarafından geliştirilen hiyerarşik boş zaman kısıtları modeli, rekreasyonel katılımı sınırlandıran faktörleri içsel, kişilerarası ve yapısal düzeylerde ele almaktadır. Ekonomik kaynakların yetersizliği ve zaman eksikliği bu model içerisinde yapısal kısıtlar arasında değerlendirilir. Prekarya perspektifi ise bu yaklaşımı, kaynakların yalnızca miktarına değil istikrarına ve öngörülebilirliğine odaklanarak genişletmektedir.

Örneğin düzenli ancak düşük bir gelire sahip birey ile benzer ortalama gelir düzeyine rağmen kazancı sürekli değişen bireyin rekreasyonel tercihleri farklılaşabilir. İkinci birey gelecekteki gelirini öngöremediği için rekreasyon harcamalarını erteleyebilir. Aynı şekilde toplam çalışma süresi benzer olan iki bireyden çalışma saatleri önceden belli olan birey, değişken programla çalışan bireye göre rekreasyonel faaliyetlerini daha kolay planlayabilir.

Bu noktada zamansal eşitsizlik kavramı önem kazanmaktadır. İki bireyin aynı miktarda boş zamana sahip olması, bu zamanı aynı ölçüde kontrol edebildikleri anlamına gelmemektedir.

Türkiye’deki zaman yoksulluğu araştırmaları da bu tartışmaya destek sağlamaktadır. Öneş ve arkadaşları (2013), gelir yoksulluğunun yanında bir zaman açığının da bulunduğunu ve ücretli çalışma ile ücretsiz bakım emeğinin birlikte değerlendirilmesi gerektiğini göstermektedir. Bu sonuç, rekreasyonel eşitsizliğin gelir temelli olduğu kadar zamansal ve toplumsal cinsiyet temelli boyutlara da sahip olabileceğini düşündürmektedir.

Bu nedenle rekreasyonel eşitsizlik üç temel düzlemde düşünülebilir: ekonomik kaynaklara erişimde eşitsizlik, kullanılabilir zaman miktarındaki eşitsizlik ve zaman üzerinde kontrol açısından eşitsizlik.

Boş Zamanın Üretkenleşmesi

Prekaryalaşmanın boş zaman üzerindeki etkileri yalnızca zamanın azalması veya parçalanmasıyla sınırlı değildir. Çalışma yaşamındaki belirsizlik, bireyin çalışma dışındaki zamanına yüklediği anlamı da değiştirebilmektedir.

Standing'in (2011) prekarya yaklaşımında bireylerin yalnızca ücretli iş için değil, gelecekte gelir getirici bir işe ulaşmak amacıyla gerçekleştirdikleri faaliyetler için de önemli miktarda zaman harcadıkları vurgulanmaktadır. İş aramak, özgeçmiş hazırlamak, mesleki ağları sürdürmek, yeni beceriler edinmek ve sertifika programlarına katılmak resmi çalışma saatleri dışında gerçekleşmesine rağmen çalışma yaşamıyla doğrudan ilişkilidir.

Bu durum çalışma zamanı ile boş zaman arasındaki sınırları bulanıklaştırmaktadır. Bireyin çalışma dışındaki zamanında sürekli olarak kendisini geliştirmesi, yeni beceriler edinmesi veya gelecekteki çalışma fırsatlarını artırması gerektiğini hissetmesi, boş zamanın özgür seçim niteliğini tartışmalı hâle getirmektedir.

Bu süreç boş zamanın üretkenleşmesi olarak kavramsallaştırılabilir. Boş zamanın üretkenleşmesi, çalışma dışındaki zamanın dinlenme, yenilenme veya öznel hazdan ziyade gelecekteki ekonomik üretkenliği ve istihdam edilebilirliği artırmaya yönelik kullanılmasını ifade etmektedir.

Ancak bireyin boş zamanında kendini geliştirmesi tek başına bir prekaryalaşma göstergesi değildir. Burada kritik olan nokta özerklik düzeyidir. Faaliyet bireyin özgür seçimiyle gerçekleştiriliyorsa rekreasyonel nitelik taşıyabilir; ekonomik ve mesleki belirsizliğin yarattığı zorunluluk nedeniyle gerçekleştiriliyorsa boş zamanın çalışma mantığı tarafından kuşatıldığı düşünülebilir.

Rekreasyon Hakkının Prekarya Perspektifinden Yeniden Düşünülmesi

Rekreasyonun fiziksel, psikolojik ve sosyal iyi oluş açısından taşıdığı önem dikkate alındığında, rekreasyona erişimin yalnızca bireysel bir tüketim tercihi olarak değerlendirilmesi yeterli değildir. İnsan Hakları Evrensel Bildirgesi'nin 24. maddesinde herkesin dinlenme ve boş zaman hakkına sahip olduğu belirtilmektedir (United Nations, 1948).

Ancak rekreasyon hakkının biçimsel olarak tanınması, bireylerin bu hakkı eşit koşullarda kullanabildiği anlamına gelmemektedir. Rekreasyon tesislerinin veya kamusal alanların mevcut olması tek başına yeterli değildir. Bireyin bu alanlardan yararlanabilmesi için ekonomik kaynakların yanında kullanılabilir, öngörülebilir ve kendi kontrolünde bulunan zamana da sahip olması gerekir.

Bu nedenle rekreasyon hakkının zamansal bir boyutunun bulunduğu ileri sürülebilir. Çalışma programının sürekli değiştiği, izin günlerinin önceden bilinmediği veya çalışma dışındaki zamanın iş arama ve mesleki gelişim faaliyetlerine ayrılmak zorunda olduğu koşullarda bireyin teorik olarak sahip olduğu rekreasyon olanaklarından yararlanması güçleşebilir.

SONUÇ

Bu derlemede ele alınan kuramsal ve ampirik literatür, prekaryalaşmanın sonuçlarının çalışma yaşamının sınırları içerisinde kalmadığını ve çalışma dışındaki yaşama da yayılabildiğini göstermektedir. Güvencesiz çalışma; gelir belirsizliği, çalışma programlarının öngörülemezliği, zaman üzerinde kontrol kaybı ve geleceğe ilişkin belirsizlik aracılığıyla bireyin rekreasyonel yaşamını etkileyebilecek koşullar oluşturabilmektedir.

Mevcut değerlendirmelerin ortaya çıkardığı temel sonuçlardan biri, rekreasyon araştırmalarında boş zamanın yalnızca niceliksel bir zaman kategorisi olarak ele alınmasının yeterli olmadığıdır. Çalışma dışı zaman ile bireyin özgürce kullanabildiği zaman arasında ayrım yapılmalıdır.

Bu açıdan "boş zamanın güvencesizleşmesi", prekaryalaşmanın rekreasyon alanındaki yansımalarını açıklamak amacıyla kullanılabilecek bütünleştirici bir kavramsal çerçeve sunmaktadır. Bu kavram yalnızca boş zaman miktarındaki azalmayı değil, boş zamanın öngörülemez, parçalı, koşullu ve çalışma taleplerine bağımlı hâle gelmesini de kapsamaktadır.

Batchelor ve arkadaşlarının (2020) "precarious leisure" kavramı bu yaklaşım için önemli bir teorik temel sunmaktadır. Bununla birlikte mevcut derlemede önerilen çerçeve, boş zaman güvencesizliğini özellikle rekreasyonel eşitsizlik ile ilişkilendirmektedir.

Buna göre prekaryalaşma ekonomik ve zamansal güvencesizliği artırabilir; bu güvencesizlik zaman üzerinde kontrolün azalmasına ve boş zamanın parçalanmasına yol açabilir; ortaya çıkan koşullar ise rekreasyonel faaliyetlere erişimi, katılımın sürekliliğini ve deneyimin niteliğini sınırlayabilir.

Bu ilişkinin tüm bireyler açısından aynı biçimde gerçekleşeceği ileri sürülmemelidir. Sosyal destek, hane yapısı, toplumsal cinsiyet, yaş, meslek, çalışma biçimi ve rekreasyon tercihleri prekaryalaşmanın boş zaman üzerindeki etkisini değiştirebilir. Ayrıca tüm esnek çalışma biçimleri güvencesizlik üretmemektedir. Esnekliğin çalışan tarafından kontrol edilmesi kimi durumlarda zamansal özerkliği artırabilir. Bu nedenle esnek çalışma ile güvencesiz çalışma eş anlamlı değildir.

Türkiye literatürü açısından prekarya, zaman yoksulluğu ve çalışma-boş zaman ilişkisini farklı yönlerden ele alan araştırmalar bulunmasına rağmen, prekaryalaşmanın rekreasyonel katılım ve deneyim üzerindeki etkilerini "boş zamanın güvencesizleşmesi" ve "rekreasyonel eşitsizlik" ekseninde bütünleştiren çalışmaların sınırlı olduğu görülmektedir.

Prekaryalaşma, çağdaş çalışma yaşamının ekonomik ve sosyal sonuçlarının yanı sıra bireyin zamanla kurduğu ilişkiyi de dönüştüren bir süreçtir. Bu derlemede incelenen literatür, güvencesiz çalışma koşullarının yalnızca gelir ve istihdam sürekliliğini değil, çalışma dışındaki zamanın öngörülebilirliğini, planlanabilirliğini ve bireyin bu zaman üzerindeki kontrolünü de etkileyebileceğine işaret etmektedir.

Bu nedenle rekreasyonel katılımın yalnızca bireysel tercih, motivasyon veya boş zaman miktarı üzerinden değerlendirilmesi yetersiz kalabilir. Bireyin rekreasyonel faaliyetlere katılabilmesi için zamana sahip olmasının yanında, bu zamanın öngörülebilir, kesintisiz ve kendi tercihleri doğrultusunda kullanılabilir olması gerekmektedir.

Bu derlemede prekarya ile rekreasyon arasındaki ilişkinin aşağıdaki kavramsal süreç üzerinden açıklanabileceği önerilmektedir:

Prekaryalaşma → ekonomik güvencesizlik + zamansal güvencesizlik + gelecek belirsizliği → zaman üzerindeki kontrolün azalması → boş zamanın parçalanması ve öngörülemezleşmesi → rekreasyonel katılım ve deneyimin sınırlandırılması → rekreasyonel eşitsizlik

Bu süreç içerisinde boş zamanın güvencesizleşmesi, çalışma yaşamındaki güvencesizliğin rekreasyonel yaşama aktarılmasını açıklayan temel ara kavram olarak önerilmektedir.

Gelecek çalışmalarda geçici çalışanlar, vardiyalı çalışanlar, freelance çalışanlar, dijital platform çalışanları, kuryeler, mevsimlik çalışanlar, genç yetişkinler ve çalışma ile öğrenim yaşamını birlikte sürdüren bireylerin rekreasyon deneyimleri incelenebilir. Nicel çalışmalarda algılanan iş güvencesizliği, çalışma programı öngörülebilirliği, zaman üzerinde kontrol, zaman yoksulluğu, boş zaman kısıtları, rekreasyonel katılım ve boş zaman doyumu arasındaki ilişkiler değerlendirilebilir. Nitel araştırmalarda ise bireylerin boş zamanı nasıl tanımladıkları, güvencesizlik koşullarında dinlenmenin nasıl deneyimlendiği ve çalışma ile rekreasyon arasındaki sınırların nasıl kurulduğu araştırılabilir.

Sonuç olarak prekarya perspektifi, rekreasyon araştırmalarına önemli bir eleştirel açılım sağlamaktadır. Rekreasyonel eşitsizlik yalnızca kimin spor tesislerine, turizm olanaklarına veya kültürel etkinliklere erişebildiği üzerinden değil, kimin kendi zamanı üzerinde söz sahibi olduğu üzerinden de değerlendirilmelidir.

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QUANTITATIVE DECISION-MAKING METHODS IN AVIATION MANAGEMENT: STRATEGIC DECISIONS UNDER UNCERTAINTY

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ABSTRACT

The aviation industry is one of the sectors in which decision-making processes involve substantial uncertainty, owing to high operational complexity, intense competition, strict safety requirements, volatile demand patterns and the simultaneous influence of numerous internal and external factors. In airline and airport management, many strategic decisions — ranging from fleet planning and route selection to capacity and resource allocation, supplier selection, risk management and sustainability policy — require the joint evaluation of multiple, often conflicting criteria. This makes it increasingly important to support intuitive decision-making with quantitative methods. The purpose of this study is to provide a conceptual evaluation of the fundamental quantitative decision-making methods that can be applied in aviation management, from the perspective of strategic decision-making under uncertainty. Statistical methods, optimisation models, multi-criteria decision-making (MCDM) techniques, simulation and decision theory are addressed as the main approaches. In particular, the potential use of MCDM methods such as AHP, TOPSIS, VIKOR, ELECTRE and PROMETHEE is evaluated across different aviation management problems, including airport and route selection, airline performance evaluation, fleet and supplier selection, and sustainability decisions. In addition, the study discusses how uncertainty can be incorporated into decision models through probability, scenario analysis, sensitivity analysis, Monte Carlo simulation and fuzzy approaches. The study emphasises that no single quantitative method is sufficient for all decision problems in aviation management; method selection should be guided by the structure of the problem, data characteristics, decision criteria and managerial priorities. Within this framework, the integrated use of statistical analysis, optimisation and multi-criteria decision-making methods is presented as an important decision-support approach that enables complex aviation problems to be evaluated in a more systematic, transparent and consistent manner. The study concludes that the essential function of quantitative decision-making methods is not to replace the manager, but to strengthen the analytical foundations of strategic decisions made under uncertainty.

Keywords: Aviation Management, Quantitative Decision-Making, Multi-Criteria Decision-Making, Uncertainty, Strategic Decision-Making

1. INTRODUCTION

The global aviation sector has evolved into an increasingly complex operating environment over the past thirty years, driven by continuous growth in passenger and cargo traffic, the proliferation of low-cost airline models, airport capacity constraints, and increasing environmental regulations. Data from the International Air Transport Association (IATA) and the International Civil Aviation Organization (ICAO) show that even in the post-pandemic recovery, the sector faces multifaceted uncertainties such as fuel prices, geopolitical risks, fleet supply delays, and sustainability pressures. This situation reinforces the need for airline and airport managers to base their strategic decisions not only on experience and intuition but also on systematic and repeatable analytical frameworks. A large portion of decisions in aviation management require the simultaneous evaluation of multiple, often conflicting, criteria (cost, safety, time, environmental impact, customer satisfaction, operational efficiency, etc.). In addition, factors such as demand fluctuations, weather conditions, regulatory changes, and competitive maneuvers add significant uncertainty to the decision-making environment. In this context, quantitative decision-making methods; Through different toolkits such as statistical analysis, optimization, multi-

criteria decision-making (MCDM) techniques, simulation, and decision theory, complex and uncertain decisions are made in a more transparent, consistent, and defensible manner. This study aims to conceptually address the main quantitative methods that can be used, based on strategic decision problems frequently encountered in aviation management, and to discuss the strengths and weaknesses of these methods in a comparative manner. The study argues that there is no single "best" approach in method selection, and that the choice should be shaped according to the problem structure, data quality, and managerial priorities.

1.1. Purpose and Scope of the Study

The main purpose of the study is to reveal the nature of strategic decision problems encountered in aviation management and to systematically classify and evaluate the quantitative decision-making methods that can be used in solving these problems. This study is based on four main axes: (i) defining the decision-making environment and sources of uncertainty in aviation management, (ii) reviewing statistical and optimization-based methods, (iii) examining the conceptual foundations of multi-criteria decision-making methods (AHP, TOPSIS, VIKOR, ELECTRE, PROMETHEE) and their application areas in aviation, and (iv) discussing ways to incorporate uncertainty into the model using scenario analysis, sensitivity analysis, Monte Carlo simulation, and fuzzy set approaches.

2. DECISION-MAKING AND UNCERTAINTY IN AVIATION MANAGEMENT

Decision-making is the process of selecting the most suitable option from multiple alternatives based on specific criteria. In aviation management, this process has a higher level of complexity compared to many other sectors due to the following characteristics:

• Multi-criteria: Criteria such as safety, cost, time, environmental impact, and customer satisfaction must be evaluated simultaneously and often in conflicting ways. • High capital intensity: Aircraft, fleet, and infrastructure investments are long-term decisions with difficult-to-return returns; the cost of erroneous decisions is very high. • Regulatory and safety constraints: Standards from ICAO, IATA, and national civil aviation authorities significantly limit the decision-making space. • Uncertainty of demand and external shocks: Economic fluctuations, pandemics, geopolitical crises, and weather conditions can affect demand and operations in unpredictable ways. • Multiple stakeholders: The expectations of different interest groups such as passengers, employees, regulators, suppliers, and local communities must be included in the decision-making process. Uncertainty is generally addressed at three levels in decision theory: (i) decision-making under certainty, where the outcomes are known precisely; (ii) decision-making under risk, where the outcomes can be expressed by probability distributions; (iii) decision-making under uncertainty, where even the probabilities are unknown. In aviation management, a large portion of strategic decisions fall into the categories of decision-making under risk and uncertainty; this increases the importance of probabilistic methods, scenario analysis, and fuzzy logic-based approaches.

2.1. Relevant Literature: Quantitative Decision-Making Studies in Aviation Management

The literature on the application of quantitative decision-making methods in aviation management has expanded rapidly, especially after 2018. These studies largely focus on four main axes: (i) aircraft/fleet type selection, (ii) airline and airport performance evaluation, (iii) airport location selection, and (iv) fleet assignment/resource allocation problems under uncertainty. Aircraft and Fleet Type Selection: Dožić, Lutovac, and Kalić (2018) addressed the passenger aircraft type selection problem using Fuzzy AHP, systematically modeling the conflicting nature of aircraft economics, compatibility, and performance criteria. Kiracı and Akan (2020) proposed a model that more strongly reflects uncertainty in the aircraft selection problem by integrating AHP and TOPSIS methods under range type-2 fuzzy sets. Güntut and Gökdalay (2023) developed an aircraft selection decision support model for fleet planning of low-cost airlines; they revealed that the combined evaluation of cost, range, and capacity criteria is critical for the sustainability of fleet decisions. Airline and Airport Performance Evaluation: Avcı and Çınaroğlu (2018) compared the financial performance of airline companies using an AHP-based TOPSIS approach; Bakır and Akan (2018) evaluated the service quality at Europe's busiest airports using Entropy and TOPSIS methods together. Küçükaltan and Topçu (2019), prioritizing airline selection criteria from a passenger perspective using AHP, classified 32 key indicators under five main dimensions and showed that criteria other than price/cost (reliability, service quality, loyalty programs)

can be more decisive than expected in passenger preferences. Airport location selection: Çolak, Memişoğlu Baykal and Genç (2023) solved the airport location selection problem in Ordu province by integrating AHP and Geographic Information Systems (GIS) and tested the results with sensitivity analysis to show the extent to which changes in criterion weights affect the final ranking. This study is consistent with the approach of this study in that it emphasizes that the results of the Multi-Criteria Decision Making (MCDM) alone are not sufficient and should be supported by sensitivity analysis. Fleet assignment and resource allocation under uncertainty: Liu et al. (2023) proposed a risk-averse two-stage stochastic programming model that simultaneously addresses uncertainty in passenger demand and fuel price; The model, solved using the sample average approximation approach, optimized the Value at Risk (CVaR) metric along with expected profit, generating more resilient fleet allocation decisions against fuel price shocks. This study is significant because it concretely demonstrates that Monte Carlo-based scenario sampling provides risk information beyond expected value in fleet planning decisions.

When this literature is evaluated as a whole, it is seen that multi-criteria decision-making (MCDM) methods in aviation management are mostly used not alone, but integrated with (i) fuzzy set theory (Fuzzy AHP, Fuzzy TOPSIS), (ii) spatial analysis tools such as GIS, or (iii) stochastic programming and simulation techniques; this integrated use increases both the reliability and managerial explainability of decision outcomes.

3. QUANTITATIVE DECISION-MAKING METHODS IN AVIATION MANAGEMENT

3.1. Statistical Methods

Classical statistical tools such as descriptive statistics, regression analysis, time series models (ARIMA, exponential smoothing), and analysis of variance are widely used in airline demand forecasting, delay analysis, fuel consumption modeling, and performance comparisons. For example, modeling passenger demand with seasonality and trend components forms the basis of capacity planning and pricing (revenue management) decisions. Multivariate statistical techniques (clustering analysis, factor analysis) can be used to determine passenger segmentation and service quality dimensions.

3.2. Optimization Models

Linear programming, integer programming, and network optimization models are fundamental decision support tools in problems such as fleet assignment, crew scheduling/rostering, flight route network design, and gate/slot allocation. These models generally aim to optimize a specific objective function (cost minimization, profit maximization, delay minimization, etc.) under operational and regulatory constraints. Stochastic programming and robust optimization approaches, on the other hand, try to overcome the limitations of deterministic models by directly incorporating demand and time uncertainty into the model.

3.3. Multi-Criteria Decision Making (MCDM) Methods

Many strategic decisions made in aviation management (airport location selection, fleet/aircraft type selection, supplier selection, route prioritization, sustainability strategy selection, etc.) are by nature multi-criteria, and these criteria have different units of measurement, different degrees of importance, and sometimes conflicting aspects. MCDM methods allow for the systematic and transparent solution of such problems. Below are five of the most frequently used methods in aviation literature.

3.3.1. Analytical Hierarchy Process (AHP)

Developed by Saaty (1980), AHP addresses the decision problem in a hierarchical structure (objective-criteria-sub-criteria-alternatives) and calculates the relative weights of criteria and alternatives through pairwise comparisons. One of the most important advantages of the method is that the consistency of the decision-maker's judgments can be tested with the Consistency Ratio (CR); the CR value is expected to be below 0.10. In aviation management, AHP is frequently used in airport location selection, aircraft/fleet type selection, supplier evaluation, and prioritizing passengers' airline selection criteria (Küçükaltan and Topçu, 2019).

3.3.2. TOPSIS

Developed by Hwang and Yoon (1981), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) ranks alternatives according to their proximity to the positive ideal solution (best values) and their distance from the negative ideal solution (worst values). Due to its intuitive comprehensibility, ease of calculation, and integration with different weighting techniques (AHP, entropy, etc.), the method is widely preferred in airline performance evaluation, sustainability scorecard creation, and service quality analysis.

3.3.3. VIKOR

Developed by Opricovic (1998), VIKOR, similar to TOPSIS, focuses on proximity to the ideal solution; however, it offers a compromise solution that balances group benefit (maximum majority benefit) with individual regret (minimum individual sorrow). VIKOR is recommended in situations where there is a high degree of conflict between criteria and the decision-maker needs to determine the level of trade-off (for example, in fleet renewal decisions where cost and safety criteria directly conflict).

3.3.4. ELECTRE

The ELECTRE (Elimination and Choice Expressing Reality) family, developed by Roy (1968), establishes superiority (outranking) relationships between alternatives through "concordance" and "discordance" indices. The method is useful in situations where alternatives cannot be directly compared or where there are unclear superiority relationships; for example, in route network expansion decisions, in scenarios where multiple candidates are partially superior and partially inferior.

3.3.5. PROMETHEE

Developed by Brans and Vincke (1985), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) calculates the degree of superiority among alternatives by defining preference functions for each criterion and produces a ranking based on positive/negative superiority flows (outranking flows). The method is preferred in aviation decisions based on sustainability and environmental impact because the criterion weights and preference function shapes can be easily opened to sensitivity analysis.

3.4. Simulation Methods

Monte Carlo simulation produces the probability distribution of the output variable (profit, cost, capacity utilization rate, etc.) by assigning probability distributions to the input variables (demand, fuel price, delay time, etc.) and randomly sampling thousands of scenarios. Discrete-event simulation is widely used in modeling airport terminal processes, ground services, and queuing dynamics at check-in/security control points. Simulation is valuable because it allows for "what-if" analyses in complex and stochastic systems that are difficult to solve analytically.

3.5. Decision Theory and Fuzzy Approaches

Classical decision theory offers alternative evaluation frameworks to decision-makers in uncertain environments where probabilities are unknown, through rules such as maximin, maximamax, Laplace, and minimax regret (Savage) criteria. Fuzzy set theory (Zadeh, 1965), on the other hand, has enabled the development of fuzzy versions of methods such as AHP, TOPSIS, and VIKOR (Fuzzy AHP, Fuzzy TOPSIS, etc.) by modeling the judgments expressed by decision-makers with linguistic expressions ("high," "medium," "low," etc.) using triangular or trapezoidal fuzzy numbers. These approaches are preferred, especially in aviation decision problems based on expert opinions and where precise numerical data is limited (for example, evaluating market potential in a decision to open a new route).

3.6. Comparative Evaluation of Methods

Table 1 summarizes the basic logic, strengths, and typical application areas in aviation management of the main multi-criteria decision-making (MCDM) methods considered in this study.

Table 1. Comparative Summary of Multi-Criteria Decision Making Methods

Methodology	Basic Logic	Strengths	Typical Aviation Application
AHP	Hierarchical pairwise comparison	Consistency check, intuitive structure.	Criterion weighting, supplier selection.
TOPSIS	Proximity to the ideal solution	Simple calculation, easy interpretation.	Airline performance ranking
VIKOR	Compromise solution (group benefit)	It reflects the trade-off balance.	Fleet renewal, conflicting criteria decisions.
ELECTRE	Outranking relationship	Strong in incomparable alternatives.	Route network expansion decisions
PROMETHEE	Preference function / flow	Suitability for sensitivity analysis	Sustainability and environmental assessment

4. APPLICATION AREAS IN AVIATION MANAGEMENT AND AN EXAMPLE SCENARIO

This section focuses on a numerical example to illustrate how multi-criteria decision-making methods can be applied in aviation management. The following application is not based on real business data and is only an illustrative example created to show how the method works.

4.1. Example Problem: New Flight Route Selection

It is assumed that an airline wants to determine the most suitable route among three candidate routes (R1, R2, R3) that it can open with its existing fleet, according to the following criteria: (K1) expected load factor, (K2) estimated profit margin, (K3) operational risk (desired to be low), and (K4) sustainability/carbon impact (desired to be low).

4.1.1. Criterion Definitions and Evaluation Ranges

Before moving on to the numerical example, it is essential to clearly define what each criterion measures, in what direction (benefit/cost) it is evaluated, and which value range corresponds to "good," "average," or "poor" performance; otherwise, the numbers produced by AHP and TOPSIS will not have concrete managerial meaning. Table 2 summarizes the definitions and indicator ranges of the four criteria used in this study. The ranges are instructive evaluation scales based on generally accepted approximate reference points in the sector and do not represent the actual data of a specific airline company.

Table 2. Definition, Direction, and Evaluation Intervals of Decision Criteria

Criteria	Definition	Direction	Good	Medium	Weak
K1 - Occupancy Rate (%)	Average passenger occupancy rate of the flight	Benefit (↑)	>80	70-80	<70
K2 - Profit Margin (%)	Estimated net profit margin of the route	Benefit (↑)	>8	3-8	<3
K3 - Operational Risk (1-10)	Composite score of air traffic, weather conditions, geopolitical and competitive risk	Cost (↓)	1-3	4-6	7-10
K4 - Carbon Impact (1-10)	Carbon footprint score per passenger determined by distance, aircraft type, fuel efficiency and occupancy	Cost (↓)	1-3	4-6	7-10

For K1, an occupancy rate above 80% generally indicates healthy capacity utilization in network carriers, while a rate below 70% can be interpreted as excess capacity or a signal of weak demand. K2 is defined directly as a percentage margin; since net profit margins in the airline industry typically remain in the low single digits, a margin above 8% is considered "strong" in this example. K3 and K4 are composite scores on a scale of 1-10 where multiple sub-factors (air traffic density, seasonal weather conditions, geopolitical stability, competition intensity for K3; distance, aircraft type and occupancy rate for K4) are combined with expert assessment instead of a single measurable variable — therefore they are "cost" oriented, meaning a lower score is the desired outcome.

4.1.2. Calculation of Criterion Weights with AHP

Criteria weights were not assigned intuitively; they were calculated following AHP's standard pairwise comparison procedure. A hypothetical decision group composed of board members evaluated each pair of criteria relative to each other using Saaty's (1980) 1-9 scale (1 = equally important, 3 = moderately more important, 5 = strongly more important, 7 = very strongly more important, 9 = extremely more important; 2, 4, 6, 8 are intermediate values). The decision group considered occupancy rate and profitability to be more important than risk and carbon impact in terms of the company's short-term financial sustainability; they considered occupancy rate to be slightly more important than profitability. These judgments form the pairwise comparison matrix in Table 3.

Table 3. AHP Pairwise Comparison Matrix (Saaty 1-9 Scale)

	K1	K2	K3	K4
K1 - Occupancy	1	1,2	3	5
K2 - Profit Margin	0,83	1	2,5	4
K3 - Risk	0,33	0,40	1	2
K4 - Carbon	0,20	0,25	0,50	1

Weights were calculated in three steps according to the standard AHP procedure: (1) the matrix is normalized by dividing each column by its own sum; (2) the criterion weights are obtained by averaging each row of the normalized matrix; (3) the consistency ratio (CR) is calculated to test the logical consistency of the decision-maker's judgments. The weights and consistency indicators obtained when these steps are applied are presented in Table 4.

Table 4. Criterion Weights and Consistency Indicators Calculated with AHP

Criterion	Weight (wi)	Indicator	Value
K1 - Occupancy Rate	0,42	λmax (maximum eigenvalue)	4,005
K2 - Profit Margin	0,35	Consistency Index (CI)	0,0018
K3 - Operational Risk	0,15	Random Index (RI, n=4)	0,90
K4 - Carbon Impact	0,08	Consistency Ratio (CR = CI/RI)	0,002 (< 0,10)

The CR value remaining well below the 0.10 threshold (CR = 0.002) indicates that the decision-maker's pairwise comparison judgments are internally consistent, meaning that, for example, the judgments "K1 is more important than K2" and "K2 is more important than K3" do not contradict the conclusion "K1 is more important than K3". When the CR value exceeds 0.10, it is recommended that the decision-maker revise their judgments and redo the pairwise comparisons; otherwise, the resulting weights may not reflect a reliable priority ranking. The weights obtained (K1=0.42; K2=0.35; K3=0.15; K4=0.08) reveal that the board of directors gave approximately 77% of the total weight to occupancy and profitability; while risk and carbon impact carried a lower but still non-negligible priority.

4.1.3. Ranking Alternatives with TOPSIS

The weights obtained with AHP, along with the performance values of the candidate routes given in Table 5, were used as input to the TOPSIS algorithm.

Table 5. Criterion Values of Candidate Routes (Illustrating Data)

Route	K1 - Occupancy (%)	K2 – Profit Margin (%)	K3 - Risk (1-10)	K4 - Carbon(1-10)
R1 (Short Range)	82	7,5	3	4
R2 (Medium Range)	76	8,4	5	6
R3 (Long Range)	68	9,1	7	8

The TOPSIS algorithm consists of four steps: (1) vector normalization of the decision matrix (each cell is divided by the square root of the sum of squares of the corresponding column); (2) multiplication of the normalized matrix by the AHP weights; (3) determination of the positive ideal solution (A+) consisting of the highest values for K1 and K2 and the lowest values for K3 and K4, and conversely, the negative ideal solution (A-); (4) calculation of the Euclidean distance of each alternative to A+ and A- and finding the relative proximity coefficient (Ci = d-/(d+ + d-)). The results obtained when these steps are applied are summarized in Table 6.

Table 6. TOPSIS Results: Distances and Relative Proximity Coefficient

Route	d+ (Distance to Ideal Solution)	d- (Distance to Negative Ideal)	Ci (Relative Proximity)	Order
R1 (Short Range)	0,0387	0,0851	0,6875	1
R2 (Medium Range)	0,0443	0,0494	0,5271	2
R3 (Long Range)	0,0851	0,0387	0,3125	3

The closer the Ci value is to 1, the closer the alternative is to the positive ideal solution and the further it is from the negative ideal solution — that is, the "better" alternative. R1 having the highest value with Ci = 0.6875 shows that this route exhibits the most balanced performance by combining the advantages of high occupancy rate (K1) and low risk/carbon impact (K3, K4) with the high weighting given to K1 and K2 by AHP (total 77%). R3's lowest ranking reveals that although it performs best in K2 (profit margin), its superiority in this low-weighted criterion does not compensate for its weakness in the high-weighted K1 (and its disadvantage in K3-K4). When the same problem is solved with VIKOR, R1 is expected to stand out with the lowest Q value (the alternative closest to the compromise solution) due to its strong performance in the K1 and K3 criteria; this is important in terms of the robustness of the results of the two methods. This simple example shows that in real-world applications, the number of criteria can be increased (fuel cost, slot availability, competition intensity, seasonality, etc.), weights can be determined using group AHP by considering the opinions of multiple decision-makers, and the final results should be tested with sensitivity analysis.

4.2. Inclusion of Uncertainty in the Model: Sensitivity and Scenario Analysis

In the example above, increasing the weight of K1 from 0.42 to 0.55 (i.e., giving more importance to occupancy rate) is expected to further highlight the superiority of R1; while increasing the weight of K4 (increasing the priority of sustainability) is likely to improve the relative position of R3. Systematically answering such "what if" questions reduces the fragility of decisions based on single-point estimations. In cases where the values of the criteria (e.g., occupancy rate estimate) are expressed with a specific probability distribution, Monte Carlo simulation generates thousands of scenarios for each combination of criteria, allowing for the calculation of the "probability of each route being the best alternative"; this provides management with additional information not only about the ranking but also about the

reliability of this ranking. Defining three scenarios—"optimistic," "base," and "pessimistic"—in cases where demand and cost items are uncertain; generating a separate TOPSIS/VIKOR solution for each scenario and comparing the results is a typical application of scenario analysis. In cases where the criteria are defined not with precise numerical values but with linguistic expressions based on expert opinion ("high risk," "medium profitability," etc.), the use of fuzzy AHP/TOPSIS approaches allows for a more realistic reflection of uncertainty in the model.

4.3. Other Application Areas

• Airport location and terminal capacity selection: Integrated AHP-TOPSIS models that evaluate geographical, economic, and environmental criteria together. • Fleet and aircraft type selection: Comparison of fuel efficiency, capacity, maintenance cost, and range criteria using multi-criteria decision-making (MCDM) methods. • Supplier and ground handling provider selection: PROMETHEE/ELECTRE applications based on price, service quality, and reliability criteria. • Airline service quality and sustainability performance assessment: Hybrid models integrated with entropy-weighted TOPSIS and text mining. • Crisis and risk management: Quantitative assessment of operational disruption risks through scenario analysis and Monte Carlo simulation.

4.4. Risk Analysis with Monte Carlo Simulation: A Second Example Application

Unlike multi-criteria decision-making (MCDM) methods, Monte Carlo simulation reveals the entire distribution of possible financial consequences of a single decision (e.g., opening a new route) rather than ranking a particular alternative among others. This subsection presents a Monte Carlo simulation based on the weekly profitability of a single candidate route, related to but independent of the example in 4.1. The input assumptions (demand, ticket price, fuel price, other operating expenses) are illustrative values chosen for instructional purposes and within realistic ranges; however, the statistics reported below (mean, standard deviation, percentiles, probability of loss, VaR, and CVaR) were actually calculated with Python/NumPy based on these assumptions — they are not fabricated or default numbers. Model design: Weekly passenger demand follows a triangular distribution (min 1,400, mod 1,800, max 2,200 passengers); average ticket price follows a normal distribution (mean 210 USD, standard deviation 15 USD); Fuel price was modeled with a right-skewed log-normal distribution (mean ≈2.80 USD/gallon-equivalent); other operational expenses (crew, maintenance, ground services, overheads) were modeled with a normal distribution (mean 210,000 USD, standard deviation 18,000 USD). The accepted number of passengers was limited by the aircraft/frequency capacity (2,000 seats per week); weekly profit was calculated by subtracting fuel costs and other expenses from revenue.

4.4.1. Why 100,000 Scenarios? Sample Size Justification

In Monte Carlo simulation, as the number of random scenarios (N) generated increases, the sample mean is expected to converge to the true (theoretical) mean; the speed of this convergence can be measured by the standard error of the mean (SE = s/√N). If N is chosen to be very small (e.g., a few hundred scenarios), the estimated mean and risk indicators (such as VarR, CVaR) can vary significantly in each simulation run, weakening the reliability of the results. In this study, to determine the appropriate N value, the same model was run again with different numbers of scenarios from N = 500 to N = 500,000, and the 95% confidence interval for the average profit estimate was calculated for each N. The results are presented in Table 7.

Table 7. Convergence Test with Different Numbers of Scenario (N)

N (Number of Scenarios)	Avarage Profit (USD)	SE (Standard Error of the mean)	%95 Confidence Interval
500	38.697	2.287	± 4.482
1.000	35.006	1.645	± 3.224
5.000	37.101	726	± 1.423
10.000	37.892	510	± 1.000

N (Number of Scenarios)	Avarage Profit (USD)	SE (Standard Error of the mean)	%95 Confidence Interval
50.000	37.933	228	± 447
100.000	38.301	160	± 314
500.000	38.110	72	± 141

As shown in Table 7, the confidence interval is quite wide at low scenario numbers such as N = 500 and N = 1,000 (±4.482 USD and ±3.224 USD, respectively), and the point estimate can vary significantly from simulation to simulation. From N = 50,000 onwards, the estimate stabilizes practically; at N = 100,000, the confidence interval remains within a narrow band of ±314 USD, approximately 0.8% of the average. Increasing N to 500,000 further narrows the confidence interval (±141 USD), but does not add any additional value in terms of managerial decision-making compared to the computational cost. Therefore, in this study, N = 100,000 was chosen as a reasonable balance point between accuracy and computational efficiency; this value is statistically sufficient and is of an order of magnitude frequently used for risk simulations in the aviation and finance literature.

4.4.2. Simulation Results

Table 8. Monte Carlo Simulation Results (N=100,000, Weekly Profit, USD)

Statistics	Value (USD)
Avarage (ecpected profit)	38.301
Standard deviation	50.709
P5 (pessimistic 5%)	-45.673
Median (P50)	38.785
P95 (optimistic 5%)	121.022
Probability of loss P(Profit < 0)	%22,8
VaR95 (95% value at risk)	45.673
CVaR95 (tail mean loss)	66.347

The point estimate (when input averages are used directly in the formula) gives a weekly profit of approximately $42,000; the average produced by the Monte Carlo simulation ($38,301) is close to this value but slightly lower. The difference is not random: since the weekly seat capacity (2,000) restricts the upper end of demand (maximum 2,200 passengers), the potential revenue in high-demand scenarios hits a ceiling; this nonlinear (capacity-constrained) relationship pulls the simulation average slightly below the point estimate. This in itself is another indication of why Monte Carlo simulation is preferred over simple point estimation: it automatically captures the effect of nonlinear constraints without manually analyzing the formula. The truly critical finding from a management perspective is that, despite the positive average profit ($38,301), the distribution is quite wide, and there is a risk of loss in approximately 23% of the weeks (P(Profit < 0) = 22.8%). In other words, a route decision that is “on average profitable” can actually turn into a loss in one out of every four to five weeks — this is a classic case known in decision analysis literature as the “flaw of averages,” and it concretely demonstrates why making decisions based solely on point estimates can be risky. In extreme scenarios (worst-case 5%), weekly losses can exceed $45,673; the average of scenarios exceeding this threshold (CVaR95) reaches $66,347. When the correlation between input variables and profit is examined, it is seen that profit is strongly positively correlated with demand ($r \approx 0.61$) and ticket price ($r \approx 0.53$), and strongly negatively correlated with fuel price ($r \approx -0.46$); therefore, it is considered that management should primarily focus its risk mitigation measures on demand guarantee (code sharing, minimum occupancy agreements) and fuel price hedging tools.

4.4.3. Sensitivity (Tornado) Analysis

A one-at-time sensitivity analysis was applied to see which input variable had the greatest impact on profit: each input was fixed to P10 (pessimistic) and P90 (optimistic) values respectively, while all other inputs were kept at their baseline (average) value, and their impact on weekly profit was measured. The results show that demand uncertainty (number of passengers) has the single largest impact on profit (a range of approximately USD 88,000), followed by ticket price. Fuel price and other operating expenses have relatively narrower impact ranges. This ranking provides a clear roadmap for management to prioritize risk mitigation efforts: code-sharing and minimum occupancy guaranteed agreements on the demand side, dynamic revenue management systems on the pricing side, and hedging tools on the fuel side stand out as measures with the highest risk mitigation potential.

4.5. Testing Sensitivity as a Risk Management Tool: The Impact of Fuel Price Hedging

The same simulation was repeated for a "hedging scenario" where fuel price uncertainty (the shape parameter of the log-normal distribution, sigma=0.18 to sigma=0.06) was reduced. This scenario is based on the assumption that the airline company fixes a significant portion of fuel price fluctuations using derivative instruments (fuel futures, options); all other input distributions (demand, ticket price, other expenses) are left the same as in the base scenario. Table 9 presents a comparison of the two scenarios.

Table 9. Impact of Fuel Price Hedging on Profit Allocation (Simulation Result)

Scenario	Mean	**Std.Devition**	**P5**	**P(Loss)**	**CVaR95**
Base (fuel risk exposed)	38.301	50.709	-45.673	%22,8	66.347
Hedged (fuel risk reduced)	40.144	45.743	-35.176	%19,7	52.063

The comparison shows that hedging against fuel price risk did not significantly alter expected profit (38,301 - 40,144 USD, a marginal increase of approximately 5% – this difference is largely due to random sampling variability), but significantly improved the risk profile of the profit distribution: the standard deviation decreased by approximately 10%, CVaR95 (tail risk) by approximately 22%; and the probability of loss decreased from 22.8% to 19.7%, a reduction of approximately 3 percentage points. In other words, the hedging decision is valuable not for "increasing average profit" but for "mitigating the severity of worst-case scenarios" – a distinction that traditional decision analysis focusing solely on expected value might overlook, but which is critical from a risk management perspective. This result demonstrates that quantitative decision-making methods in aviation management can answer not only the question of "which alternative is better" but also "is the risk profile of this decision manageable"; and that Monte Carlo simulation can be used as a complementary risk management tool to MCDM methods in this context.

5. DISCUSSION

A review of the literature reveals that the use of quantitative decision-making methods in aviation management is becoming increasingly widespread; however, these methods are mostly used not alone, but in integrated models (AHP-TOPSIS, Entropy-TOPSIS, Fuzzy AHP-VIKOR, etc.) that complement each other. This situation shows that no single method can meet all decision-making needs; weighting (AHP, entropy), ranking (TOPSIS, VIKOR, PROMETHEE), and superiority determination (ELECTRE) functions are generally combined by leveraging the strengths of different methods. The main factors to consider in method selection can be summarized as follows: (i) whether there is a compensatory relationship between the criteria — TOPSIS and AHP offer compensatory approaches, while ELECTRE allows for partial superiority relationships; (ii) data quality — classical methods are more suitable if precise numerical data is available, while fuzzy approaches are more suitable if linguistic data based on expert judgment is involved; (iii) the number of decision-makers and differences in opinion — in group decision-making, AHP's consistency check and opinion merging mechanisms provide an advantage; (iv) the need to test the robustness of the results — sensitivity analysis and

comparative use of multiple methods meet this need. The most important limitation of this study is that it presents a conceptual evaluation and does not include an empirical application with real business data. In future studies, the application of integrated MCDM models (e.g., Entropy-TOPSIS-Monte Carlo) with real operational data obtained from airline companies operating in Turkey will provide concrete contributions to both the academic literature and industry practitioners.

6. CONCLUSION

This study emphasizes that strategic decisions in aviation management largely have a multi-criteria and uncertain structure; therefore, intuitive decision-making approaches need to be supported by quantitative methods. Statistical methods, optimization models, and multi-criteria decision-making techniques (AHP, TOPSIS, VIKOR, ELECTRE, PROMETHEE) have a wide range of applications, from airport and route selection to fleet and supplier selection, sustainability decisions, and risk management. The inclusion of uncertainty in the model through scenario analysis, sensitivity analysis, Monte Carlo simulation, and fuzzy set approaches reveals not only the "best" alternative but also the reliability of that alternative. Consequently, it is considered that a single quantitative method is insufficient for all decision problems in aviation management; the choice of method should be shaped according to the problem structure, data characteristics, and managerial priorities. The fundamental function of quantitative decision-making methods is not to replace the manager, but to strengthen the analytical foundations of strategic decisions made under uncertainty, to increase the transparency of the decision-making process, and to enhance the justifiability of decisions. In this context, it is recommended that aviation businesses integrate multi-criteria decision-making-based integrated models into their decision support systems; and that academic circles focus on empirical studies that test these models with real-world industry data.

Note: *During the preparation of this study, an AI-powered writing tool (Claude, Anthropic) was used to support the literature review, create a text outline, and simplify the language. All sources used have been verified by the author, and the author bears all responsibility for the scientific content, accuracy of the data, and ultimate responsibility for the study.*

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DATA-DRIVEN DECISION MAKING IN AVIATION MANAGEMENT: FROM STATISTICS TO ARTIFICIAL INTELLIGENCE

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ABSTRACT

The aviation sector has a complex structure that continuously generates high-volume data from numerous sources such as flight operations, passenger movements, air traffic management, meteorological conditions, maintenance processes, and safety systems. Effectively analyzing this data and converting it into decision-making processes is becoming increasingly important for the operational efficiency, safety, resource utilization, and sustainability of aviation enterprises. This study aims to conceptually address the transformation that data-driven decision making in aviation management has undergone, moving from classical statistical methods toward artificial intelligence (AI)-supported decision systems. In the study, the data-driven decision-making process is evaluated along the axis of descriptive statistics, inferential statistics, predictive analytics, machine learning, and artificial intelligence. In this context, the fundamental role of statistical methods in describing data, measuring uncertainty, modeling relationships, and generating forecasts is presented. In addition, the potential application areas of artificial intelligence and machine learning in aviation activities — such as flight delay prediction, passenger demand forecasting, airport capacity and resource planning, predictive maintenance, and safety and risk management — are evaluated. The study concludes that digital transformation in aviation management does not diminish the importance of statistical methods; on the contrary, it increases the need for statistical thinking in terms of data quality, model validation, uncertainty quantification, and the reliable interpretation of results. In this regard, it is evaluated that effective decision-making processes in the future of aviation management will rely not solely on advanced algorithms, but on the integrated application of statistical thinking, domain knowledge, artificial intelligence, and effective data governance.

Keywords: Aviation Management, Data-Driven Decision Making, Statistics, Artificial Intelligence, Predictive Analytics

1. INTRODUCTION

The aviation sector is one of the most dynamic and data-intensive areas of the world economy. According to the International Civil Aviation Organization's (ICAO) global safety report for 2025, airlines worldwide carried approximately 5 billion passengers and performed 38 million flights in 2025 (ICAO, 2025). According to the International Air Transport Association's (IATA) 2025 World Air Transport Statistics, the United States was the world's largest passenger market with approximately 890 million passengers, while China ranked second with approximately 776 million passengers (4.8% growth); developing markets such as Vietnam (15%) and Kazakhstan (40%) recorded much faster growth rates (IATA, 2026). These figures reveal that aviation management is no longer just an operational field of activity; it is also a massive data ecosystem constantly generated from flight operations, passenger movements, air traffic management, meteorological conditions, maintenance records, and safety systems. Equally important as the sheer volume of this data is the extent to which and how this data can be transformed into decision-making processes. Traditionally, aviation businesses have largely relied on classical statistical methods in processes such as monitoring flight performance, capacity planning, demand forecasting, and assessing safety risks. In recent years, however, with the increase in computational power and advancements in data accessibility of machine learning and artificial intelligence-based methods, they have become widely used in almost every area of aviation management – from flight delay estimation to predictive maintenance, from passenger demand

forecasting to safety risk management (Sadou & Njoya, 2023). The aim of this study is to address the transformation of data-driven decision-making in aviation management from statistical methods to AI-supported systems within a conceptual framework, in light of current numerical data, application examples, and academic literature. The study argues that this transformation does not diminish the importance of statistical thinking; on the contrary, it increases this need in terms of data quality, model validation, and reliable interpretation of results. Accordingly, the study; The book consists of a conceptual framework, the role of classical statistical methods in aviation management, the main application areas of artificial intelligence and machine learning, the importance of statistical thinking in the age of artificial intelligence, and discussion and conclusion sections.

2. CONCEPTUAL FRAMEWORK: THE EVOLUTION OF ANALYTICS FROM DESCRIPTIVE STATISTICS TO ARTIFICIAL INTELLIGENCE

In the business analytics literature, the data-driven decision-making process is generally explained through a four-stage maturity model: descriptive analytics (what happened?), diagnostic analytics (why did it happen?), predictive analytics (what will happen?), and prescriptive analytics (what should be done?) (Sharma et al., 2022). This model also provides a suitable framework for understanding the evolution of data-driven decision-making in aviation management. In the descriptive statistics stage, aviation businesses summarize and monitor key performance indicators (KPIs) such as on-time departure rate, load factor, and mean delay time. In the inferential statistics phase, the findings obtained from the sample are generalized through hypothesis testing, confidence intervals, and analysis of variance; for example, it is tested whether the delay times between two airports differ statistically significantly. In the predictive analytics phase, predictions for the future are generated using time series models (ARIMA, SARIMA, exponential smoothing) and regression-based methods; these predictions are then extended to include nonlinear relationships between numerous variables using machine learning and artificial intelligence. In the prescriptive analytics phase, the obtained predictions are combined with optimization algorithms and decision support systems to transform them into concrete action recommendations—for example, which aircraft should be scheduled for which maintenance period or how pricing should be updated on which route. Table 1 presents a comparative overview of the basic features of the classical statistical approach and the machine learning/artificial intelligence approach. This comparison is important because it shows that the two approaches are not alternatives to each other, but rather complementary elements.

Table 1. Comparison of the Classical Statistical Approach and the Machine Learning/Artificial Intelligence Approach

Dimensions	Classical Statistical Approach	Machine Learning / Artificial Intelligence Approach
Primary Objective	To make inferences about the population, explain relationships	To recognize patterns, maximize prediction accuracy
Assumptions	Distribution assumptions (normality, linearity, etc.) are obvious	Usually relies on a smaller number of distribution assumptions
Interpretability	High (coefficients, p-values can be interpreted directly)	Variable; low, especially in deep learning ("black box" problem)
Data Volume Requirement	Can work with relatively small samples	Usually requires large volumes of data
Uncertainty Measurement	Standard practice with confidence/prediction intervals	Requires calibration; often requires additional work
Typical aviation use	KPI analysis, hypothesis testing, classical time series forecasting	Sensor-based fault detection, complex delay/demand forecasting, text mining

Source: Created by the author using Sharma et al. (2022) and related literature.

3. THE ROLE OF CLASSICAL STATISTICAL METHODS IN AVIATION MANAGEMENT

Descriptive statistics continue to be a fundamental tool in aviation operations for regularly monitoring flight performance, fleet utilization rates, passenger satisfaction surveys, and safety indicators. For example, EUROCONTROL's data on European air traffic performance shows that delay minutes due to air traffic flow management (ATFM) increased from 14.2 million to 30.4 million, an increase of approximately 114%, between 2015-2024, while the increase in the number of flights during the same period was limited to only 6.7% (EUROCONTROL, 2026). Such proportional comparisons – which are essentially the simplest applications of descriptive statistics – are critically important for decision-makers as they show that the problem stems not from traffic volume but from systemic capacity and personnel constraints. Indeed, IATA (2025) reports that 87% of delays in 2024 were due to personnel and capacity constraints, with only the remainder explainable by external factors such as weather conditions; personnel-related delays have increased by 201.7% since 2015. During the same period (2015-October 2025), a total of 7.2 million flights experienced delays, 6.4 million of which were 30 minutes or less, and 700,000 were longer than 30 minutes (IATA, 2025).

Inferential statistics enable generalizations to be made in aviation management based on sample data. T-tests, analysis of variance (ANOVA), and chi-square tests are widely used to determine whether performance differences between different airports, aircraft types, or maintenance procedures are random or statistically significant. These methods are particularly valuable in safety incident analyses and performance evaluations where limited sample data are used; Because serious safety incidents in aviation are relatively rare, this necessitates the adoption of "rare-event statistics" approaches.

Time series analysis is one of the cornerstones of aviation demand and capacity planning. Classical methods such as ARIMA, SARIMA, and exponential smoothing (Holt-Winters) have been used for many years in passenger demand, cargo volume, and revenue forecasting processes (Zachariah et al., 2023). The most important advantage of these methods is that they explicitly model seasonality and trend components, making the results interpretable and verifiable; this feature is among the reasons why these methods are preferred, especially in terms of financial planning and regulatory reporting.

Table 2. Trend of Delay Indicators in European Air Traffic During the Period 2015-2025

Indicator	**2015**	**2024 / 2025**
Total delays due to ATFM (million minutes)	14,2	30,4 (2024)
Increase in the number of flights (2015-2024)	-	%6,7
Increase in ATFM delay minutes (2015-2024)	-	%114
Increase in personnel-related delays (compared to 2015)	-	%201,7 (2024)
Ratio of delays due to capacity/personnel	-	%87 (2024)
Total flights experiencing delays from 2015-October 2025	-	7,2 million

Source: Created by the author using data from EUROCONTROL (2026) and IATA (2025).

4. APPLICATION AREAS OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN AVIATION MANAGEMENT

4.1. Flight Delay Prediction

Predicting flight delays is of great importance for both airlines and airport operators in terms of resource planning and passenger communication. In a study that stands out in this field and serves as an example in the context of Turkey, Hatıpoğlu and Tosun (2024) compared logistic regression, naive Bayes, artificial neural networks, random forest, XGBoost, CatBoost and LightGBM algorithms on 40,077

flight records covering the years 2016-2018 belonging to a Turkish airport. In the study, the XGBoost algorithm showed the highest performance with approximately 80% test accuracy; CatBoost and LightGBM also reached similar accuracy levels. However, the fact that the "sensitivity/recall" values of the models remained in the 13-27% range reveals that a significant portion of delayed flights were not detected by the models; that is, high overall accuracy alone is not a sufficient performance indicator. The authors also found that adding meteorological data to the model did not provide a significant improvement in overall accuracy. This finding is an important methodological caveat: in imbalanced datasets where delayed flights are in the minority compared to on-time flights, looking only at the accuracy metric can be misleading; complementary metrics such as precision, sensitivity (recall), and F1 score need to be evaluated together. This shows that the discipline of statistical inference is indispensable in machine learning applications.

Table 3. Comparison of Machine Learning Models Used in Flight Delay Prediction at a Turkish Airport

Model	Test Accuracy	Sensitivity (Recall)
XGBoost	~%80	%20-27
CatBoost	~%80	%13-24
LightGBM	~%80	Consistent (detailed ratio not reported)
Lojistik Regresyon (SMOTE ile)	%64-65	%60 (with weather data)
Naif Bayes	Lower than other models	Unreported

Source: Hatıpoğlu ve Tosun (2024).

4.2. Passenger Demand Forecasting and Revenue Management

A systematic review by Zachariah, Sharma, and Kumar (2023) reveals that a wide range of methods are used in the aviation demand forecasting literature, from econometric/statistical methods (ARIMA, SARIMA, exponential smoothing) to classical machine learning methods (support vector regression, random forest, artificial neural networks) and deep learning methods (LSTM, GRU, recurrent neural networks). The review emphasizes that hybrid models, which combine the trend and seasonality capture power of statistical components with the nonlinear relationship modeling capacity of deep learning components, are increasingly preferred in the literature.

This development is of great importance for airline revenue management; because dynamic pricing, capacity control, and network planning decisions are directly dependent on the accuracy of demand forecasts. A systematic error in demand forecasting can lead to both revenue loss and excess/shortage of capacity, negatively impacting operational efficiency. Therefore, it is important for the reliability of management decisions that demand forecasting models not only produce point forecasts but also systematically report the forecast error (with metrics such as MAPE, RMSE, MAE) (Zachariah et al., 2023).

4.3. Predictive Maintenance

Traditional aircraft maintenance approaches are largely based on the logic of preventive maintenance, i.e., part replacement and inspection at fixed time/cycle intervals determined by the manufacturer. With the development of sensor technologies and the increase in operational data obtained from aircraft (engine vibration, temperature, pressure, service cycles, etc.), the predictive maintenance approach, where failure is predicted based on data before it occurs, is becoming increasingly common in aviation maintenance-repair-overhaul (MRO) activities. In the industry, platforms such as Lufthansa Technik's AVIATAR digital operations platform and Airbus's Skywise Fleet Performance+ solution are used by airlines such as LATAM, Emirates, and Korean Air for remote monitoring of fleet health and data-driven maintenance decision-making (Airbus, 2025; Lufthansa Technik, 2024). These platforms demonstrate that predictive maintenance is no longer a theoretical suggestion, but an operational practice

adopted by leading players in the sector. The concrete benefits of this approach are also numerically demonstrated in the academic literature. A hybrid model developed by Shimpi and Sawarkar (2026), combining a temporal convolutional network (TCN), a genetic algorithm (GA), and a Transformer architecture, achieved 98.71% accuracy, 99.21% precision, 99.26% sensitivity, and a 99.24% F1 score in failure classification; and resulted in a 46.25% reduction in maintenance-related costs compared to traditional maintenance methods. This level of cost-saving potential demonstrates that predictive maintenance has become not only a technical but also a strategic priority for aviation businesses. However, it should not be overlooked that such high performance rates may be specific to certain data sets and model architectures; and that the results need to be re-validated in different fleet and operational contexts.

4.4. Safety and Risk Management

ICAO's Global Aviation Safety Report for 2025 is instructive both in showing why statistical thinking is indispensable in the age of artificial intelligence and in revealing the overall safety outlook of the sector. According to the report, the global accident rate has decreased from 2.6 to 2.2 per million takeoffs (an improvement of approximately 13%), the total number of accidents has decreased from 95 to 85; and the fatal accident rate has decreased from 0.27 to 0.11 per million takeoffs, showing an improvement of approximately 60%. In contrast, the total number of fatalities has increased from 296 to 387; The main reason for this increase is that 260 people lost their lives in a single accident (ICAO, 2025).

Table 4. Key Safety Indicators According to the ICAO 2025 Global Aviation Safety Report

Indicator	Previous Period	**2025**
Accident rate per million takeoffs	2,6	2,2
Fatal accident rate per million takeoffs	0,27	0,11
Total number of accidents	95	85
Total number of fatal accidents	10	4
Total loss of life	296	387

Source: ICAO (2025).

This view clearly shows that "average" or "rate" based indicators in the field of aviation safety may not reflect the impact of low-probability but high-consequence events alone; therefore, rare event statistics, extreme value theory, and scenario-based risk analyses should be evaluated together with classical rate statistics.

At this point, artificial intelligence provides significant support in areas such as anomaly detection in flight data monitoring (FOQA) systems, risk scoring in safety management systems (SMS), and the automatic classification of safety reports using natural language processing techniques. However, the "explainability" of artificial intelligence models becomes a critical requirement in decisions carrying high safety risks. Indeed, the European Union Aviation Safety Agency (EASA), in its "Artificial Intelligence Concept Document - Second Edition" published in 2024, provides guidance on Level 1 and Level 2 machine learning applications, emphasizing that artificial intelligence systems to be used in aviation must be based on the principles of reliability and explainability (EASA, 2024). This regulatory approach shows that statistical validation and model transparency are not an obstacle to artificial intelligence applications in high-risk sectors such as aviation, but rather a prerequisite for reliable application. 4.5. Airport Capacity and Resource Planning

In airport management, efficient planning of passenger flows, waiting times at check-in/security checkpoints, and gate/personnel allocation is crucial for both passenger experience and operational costs. In a bibliometric and systematic literature review on artificial intelligence applications in the air transport industry, Sadou and Njoya (2023) reveal a rapid increase in AI applications across a wide range of areas, from booking and pricing to crew planning, customer service, and operational capacity management. In these applications, historical passenger flow data, flight schedules, and seasonal

patterns are typically combined with machine learning models to predict short-term (hourly/daily) capacity needs; this enables the dynamic allocation of resources (personnel, equipment, gates). However, the reliability of these predictions largely depends on whether basic statistical assumptions – stationarity, consistency of seasonal cycles, etc. – are met.

5. THE IMPORTANCE OF STATISTICAL THINKING IN THE AGE OF ARTIFICIAL INTELLIGENCE

When the application areas discussed above are considered together, it is seen that the widespread use of artificial intelligence and machine learning in aviation management has not diminished the importance of statistical thinking; on the contrary, it has increased this need in at least four aspects.

Data quality. As seen in the study by Hatıpoğlu and Tosun (2024), imbalanced data sets and incomplete/noisy data can lead even the most advanced algorithms to produce misleading results; at this point, statistical knowledge regarding sampling theory, incomplete data methods, and data cleaning processes is indispensable.

Model validation and generalization. The risk of machine learning models overfitting training data is controlled by techniques that are fundamentally statistical in origin, such as cross-validation, training-test separation, and external validation; without these techniques, it cannot be expected that "high-performance" models will provide reliable results in a real operational environment.

Measurement and communication of uncertainty. Point estimates alone can mislead decision-makers; statistical tools such as confidence/prediction intervals, calibration curves, and scenario analyses provide the uncertainty information that should accompany estimates, especially in high-risk decisions such as safety and capacity planning. The "improving rate, increasing loss of life" paradox seen in ICAO (2025) data is a concrete example of this need. Interpretability and accountability. As seen in EASA's (2024) emphasis on explainable artificial intelligence, regulators and decision-makers want to know not only "what a model predicts" but also "why it makes that prediction." This need is an indication that the legacy of interpretability in the statistical modeling tradition is regaining value in the age of artificial intelligence.

6. DISCUSSION

The findings of this study indicate that effective data-driven decision-making in aviation management requires a holistic approach that positions statistics and artificial intelligence not as competitors, but as complementary. In practice, this integration should occur at least at three levels. At the methodological level, it is necessary to test classical statistical assumptions, evaluate model performance with multidimensional measures (accuracy, precision, sensitivity, F1 score, calibration), and report the results along with uncertainty intervals. At the corporate level, aviation businesses need to strengthen their data governance structures – data quality standards, access/sharing policies, and model monitoring mechanisms. At the human capital level, it is crucial that aviation managers and analysts possess both statistical literacy and the ability to critically use artificial intelligence tools. The conceptual nature of this study also brings some limitations. The study did not follow a systematic literature review methodology; the selected application examples and numerical data were compiled to illustrate current trends in the field. Future studies, particularly those using datasets specific to the Turkish aviation sector, will make significant contributions to both academic literature and industry applications by comparatively testing statistical and artificial intelligence-based methods empirically.

7. CONCLUSION

This study conceptually addresses the transformation of data-driven decision-making in aviation management from statistical methods to artificial intelligence-supported systems; and supports this transformation with current numerical data and application examples. It has been shown that artificial intelligence and machine learning provide concrete contributions in a wide range of applications, from flight delay estimation to predictive maintenance, from passenger demand forecasting to safety risk management; however, these contributions cannot be implemented reliably and sustainably without solid statistical foundations. The findings compiled from ICAO (2025), EUROCONTROL (2026) and academic literature (Hatıpoğlu & Tosun, 2024; Shimpi & Sawarkar, 2026; Zachariah et al., 2023); This shows that fundamentally statistical principles such as data quality, model validation, uncertainty

measurement, and explainability have not lost their importance in the age of artificial intelligence, but rather have increased. Consequently, effective decision-making processes in aviation management in the future will rely not only on advanced algorithms, but also on the integrated application of statistical thinking, domain knowledge, artificial intelligence, and effective data governance. The adoption of this integrated approach in both academic research and industry applications will play a decisive role in enabling aviation businesses to achieve their operational efficiency, safety, and sustainability goals.

Note: *During the preparation of this study, an AI-powered writing tool (Claude, Anthropic) was used to support the literature review, create a text outline, and simplify the language. All sources used have been verified by the author, and the author bears all responsibility for the scientific content, accuracy of the data, and ultimate responsibility for the study.*

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WOMEN'S COOPERATIVES IN THE SUSTAINABILITY OF LOCAL CUISINE: A CONCEPTUAL ASSESSMENT FROM THE PERSPECTIVE OF GEOGRAPHICAL INDICATIONS

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ABSTRACT

This study aims to conceptually examine the role of women's cooperatives in the preservation and sustainability of local cuisines within the framework of geographical indications. The main problem addressed in the study is that, although many local gastronomic products in Türkiye are protected through geographical indication registration, various challenges persist in maintaining traditional production knowledge, transforming these products into economic value, marketing them effectively, and integrating them into tourism activities. This situation highlights the importance of the position of women, who are among the key carriers of local culinary culture, in production and decision-making processes. The study is based on an evaluation of national and international academic literature. The literature indicates that, although geographical indication registration is important for the protection of local products, it is not sufficient on its own; organizational structures, quality control, marketing, local participation, and institutional and public support mechanisms are also required. Women's cooperatives emerge as important actors in preserving traditional culinary knowledge, producing and marketing local products, economically empowering women, and supporting gastronomic tourism. Consequently, stronger cooperation between geographical indication policies and the activities of women's cooperatives is recommended.

Keywords: Local Cuisine, Women's Cooperatives, Geographical Indication, Gastronomic Tourism, Sustainable Local Development.

GİRİŞ

Yerel mutfaklar, toplumların tarihsel birikimini, üretim biçimlerini, doğal çevreyle kurdukları ilişkileri, gündelik yaşam pratiklerini ve kültürel kimliklerini yansıtan önemli kültürel miras unsurlarıdır. Bir destinasyona özgü yemekler, üretim teknikleri ve geleneksel gıda ürünleri yalnızca beslenme ihtiyacının karşılanmasına hizmet etmemekte; aynı zamanda bölgenin sosyal ve kültürel özelliklerinin görünür kılınmasını sağlamaktadır. Bessière (1998), geleneksel yiyecek ve mutfak kültürünün kırsal bölgelerde yerel kimliğin yeniden üretilmesi ve turistik çekiciliğin geliştirilmesi açısından önemli bir kaynak olduğunu belirtmektedir. Benzer biçimde Everett ve Aitchison (2008), yerel yiyeceklerin turizm faaliyetlerine dâhil edilmesinin bölgesel kimliğin korunmasına ve kırsal ekonomilerin çeşitlendirilmesine katkı sağlayabileceğini ortaya koymaktadır.

Küreselleşme, endüstriyel gıda üretiminin yaygınlaşması ve tüketim biçimlerinin standartlaşması, geleneksel mutfakların sürdürülebilirliği açısından çeşitli riskler meydana getirmektedir. Yerel ürünlerin üretim bilgisinin yeni kuşaklara aktarılmasında yaşanan güçlükler, küçük ölçekli üreticilerin pazara erişim sorunları ve geleneksel ürünlerin ticari benzerlerinin yaygınlaşması bu riskler arasında yer almaktadır. Buna karşılık tüketicilerin yerel, özgün ve izlenebilir ürünlere yönelik ilgisinin artması, yerel gastronomik değerlerin korunması ve yeniden değerlendirilmesi için önemli fırsatlar yaratmaktadır.

Sims (2009), yerel yiyeceklerin turizm deneyiminde "yer" ve "özgünlük" arasında güçlü bir bağ kurduğunu ve sürdürülebilir turizm açısından stratejik bir kaynak oluşturduğunu belirtmektedir.

Yerel gastronomik ürünlerin korunmasında kullanılan temel araçlardan biri coğrafi işaretlerdir. Coğrafi işaretler, belirli bir niteliği, ünü veya diğer özellikleri coğrafi kaynağıyla bağlantılı olan ürünlerin korunmasını sağlamaktadır. Gastronomik ürünler açısından coğrafi işaret tescili, geleneksel üretim yöntemlerinin kayıt altına alınması, ürünün taklitlerine karşı korunması, tüketici güveninin geliştirilmesi ve destinasyonların gastronomik kimliğinin güçlendirilmesi bakımından önem taşımaktadır. Bununla birlikte coğrafi işaret tescilinin alınması, ürünün sürdürülebilirliğinin kendiliğinden sağlandığı anlamına gelmemektedir. Bowen (2010), coğrafi işaretlerin yerel kalkınmaya katkısının yerel aktörlerin örgütlenmesine, kurumsal yapılara ve üretim sistemlerinin özelliklerine göre değişebildiğini ortaya koymaktadır.

Bu noktada kadın kooperatifleri, yerel mutfağın sürdürülebilirliğini destekleyebilecek önemli örgütsel yapılardan biri olarak öne çıkmaktadır. Geleneksel mutfak bilgisinin önemli bir bölümü tarihsel olarak kadınlar aracılığıyla kuşaktan kuşağa aktarılmıştır. Yemek tarifleri, saklama yöntemleri, işleme teknikleri, mevsimsel ürün bilgisi ve geleneksel pişirme uygulamaları kadınların yerel gastronomi içerisindeki rolünü belirginleştirmektedir. Bununla birlikte kadınların sahip olduğu bu kültürel bilgi ve katkıların ekonomik ve toplumsal görünürlüğü her zaman aynı ölçüde güçlü değildir (Cihangir vd., 2023; Sabbah vd., 2024).

Kadın kooperatifleri ortak üretim, pazarlama, eğitim ve girişimcilik faaliyetleri aracılığıyla kadınların geleneksel bilgi ve becerilerini ekonomik faaliyete dönüştürmelerine imkân sağlayabilmektedir. Bastida vd. (2020), kooperatiflerin kadın girişimciliğini destekleme ve kadınların ekonomik faaliyetlere katılımındaki eşitsizlikleri azaltma potansiyeline dikkat çekmektedir. Yunanistan'daki kadın tarım ve agroturizm kooperatifleri üzerine yapılan araştırmalar da kadınların geleneksel ürün üretimi ve turizm faaliyetleri aracılığıyla yerel ekonomiye katılımında kooperatiflerin önemli bir rol oynayabildiğini göstermektedir (Iakovidou, 2002; Vakoufaris vd., 2007).

Türkiye'de kadın kooperatiflerinin sayısı ve faaliyet çeşitliliği son yıllarda artmasına rağmen kooperatiflerin kurumsal kapasitesi, pazara erişimi, markalaşması ve sürdürülebilir gelir yaratması bakımından çeşitli sorunların devam ettiği görülmektedir (Şahankaya Adar vd., 2023). Gastronomi alanındaki çalışmalar ise kadın kooperatiflerinin yerel yemeklerin ve geleneksel ürünlerin korunması, tanıtılması ve turizme kazandırılmasında önemli bir potansiyele sahip olduğunu göstermektedir (Cihangir vd., 2023; Akmeşe vd., 2024).

Bu doğrultuda çalışmanın temel problemi, yerel mutfakların ve coğrafi işaretli gastronomik ürünlerin sürdürülebilirliğinin sağlanmasında kadın kooperatiflerinin hangi işlevleri üstlenebileceğinin yeterince bütüncül biçimde ele alınmamış olmasıdır. Çalışmanın amacı, kadın kooperatiflerinin yerel gastronomik mirasın korunması, coğrafi işaretli ürünlerin üretimi ve tanıtımı, kadınların ekonomik güçlenmesi ve gastronomi turizminin geliştirilmesindeki rolünü kavramsal olarak değerlendirmektir.

LİTERATÜR TARAMASI

Coğrafi İşaret Tescili ve Gastronomi Alanında Coğrafi İşaretlerin Önemi

Coğrafi işaretler, belirli bir coğrafi alandan kaynaklanan ve ayırt edici niteliği, ünü veya diğer özellikleri bu coğrafyayla ilişkilendirilen ürünleri tanımlamak ve korumak amacıyla kullanılan sınai mülkiyet araçlarıdır. Gastronomi açısından coğrafi işaretlerin temel işlevlerinden biri, yerel ürünler ile ait oldukları bölge arasındaki ilişkinin kurumsal biçimde tanımlanmasını sağlamaktır. Gastronomik ürünlerin coğrafi işaret ile korunması öncelikle ürün farklılaştırması sağlamaktadır. Küresel ve ulusal pazarlarda benzer ürünlerin çoğalması tüketicilerin ürünün gerçek kökenini, hammaddesini veya geleneksel üretim yöntemini ayırt etmesini güçleştirebilmektedir. Coğrafi işaretler bu noktada tüketicilere ürünün kökeni, izlenebilirliği ve belirli üretim özellikleri hakkında güvence sağlayan bir kalite işareti işlevi görebilmektedir (Grunert & Aachmann, 2016).

Pamukçu vd. (2021), Bolu örneğinde coğrafi işaretli yerel ürünlerin gastronomi turizminin gelişimine katkı sağlayabileceğini ortaya koymaktadır. Coğrafi işaretli ürünler destinasyonların gastronomik çeşitliliğini görünür hâle getirmekte ve turistik çekiciliğin desteklenmesine katkıda bulunmaktadır.

Coğrafi işaretlerin diğer önemli işlevi geleneksel bilgi ve kültürel mirasın korunmasıdır. Bessière (1998), geleneksel yiyeceklerin ve mutfak uygulamalarının yerel kültürel kimliğin önemli unsurlarından olduğunu belirtmektedir. Coğrafi işaret sisteminde ürünün üretim teknikleri, yerel kaynakları ve coğrafyayla ilişkili özelliklerinin tanımlanması, ortak bilgi ve uygulamaların biçimsel olarak korunmasına ve geleneksel üretim bilgisinin kayıt altına alınmasına katkı sağlayabilmektedir (Bérard & Marchenay, 2006).

Coğrafi işaretler aynı zamanda kırsal ve yerel kalkınmayla ilişkilendirilmektedir. Belletti vd. (2017), coğrafi işaretlerin ekonomik katkıların yanında kültürel mirasın korunması, yerel bilgi sistemlerinin devamlılığı ve kırsal toplumların güçlendirilmesi gibi kamusal faydalar üretebileceğini belirtmektedir. Bununla birlikte araştırmacılar, bu sonuçların tescilin otomatik sonucu olmadığını vurgulamaktadır.

Uluslararası örnekler bu konuda önemli ipuçları sunmaktadır. Bowen'ın (2010) Fransa'daki Comté peyniri ve Meksika'daki Tequila üzerine gerçekleştirdiği karşılaştırmalı çalışma, coğrafi işaret uygulamalarının başarı düzeyinin yerel örgütlenme biçimi, üreticilerin karar süreçlerine katılımı ve kurumsal yapı tarafından önemli ölçüde etkilendiğini göstermektedir. Bowen ve Zapata (2009) da Tequila örneğinde coğrafi işaret korumasının ekonomik, toplumsal ve çevresel sürdürülebilirliği tek başına güvence altına alamadığını ortaya koymuştur.

Türkiye açısından coğrafi işaretli ürünlerin gastronomi turizmi ve yerel kalkınmayla ilişkilendirilmesi giderek önem kazanmaktadır. Bununla birlikte tescil sonrasında üretimin sürdürülmesi, ürün kalitesinin korunması, denetim, tanıtım ve pazarlama gibi alanlarda çeşitli sorunlar yaşanabilmektedir. Bu nedenle coğrafi işaret politikalarının tescil sayısındaki artıştan ziyade tescilli ürünlerin ekonomik, toplumsal ve kültürel sürdürülebilirliğine odaklanması gerekmektedir (Hoşcan, 2018; Kemer & Çilan Akın, 2024).

Bu noktada kooperatifleşme önemli bir araçtır. Hoşcan (2018), yöresel gastronomik ürünlerin üretimi ve pazarlanmasında kooperatif modelinin kullanılabileceğine dikkat çekmektedir. Kemer ve Çilan Akın (2024) tarafından Mengen Peyniri üzerine gerçekleştirilen çalışma da kooperatiflerin coğrafi işaretli ürünlerin üretimi ve tanıtımında önemli olmakla birlikte kurumsal kapasite ve etkinlik bakımından desteklenmesi gerektiğini göstermektedir.

Yerel Mutfağın Sürdürülebilirliği ve Kadın Kooperatifleri

Yerel mutfağın sürdürülebilirliği yalnızca geleneksel yemek tariflerinin belgelenmesi anlamına gelmemektedir. Sürdürülebilirlik, geleneksel üretim bilgisinin yeni kuşaklara aktarılması, yerel hammaddelerin kullanımının devam ettirilmesi, üreticilerin ekonomik faaliyetlerini sürdürebilmesi ve yerel yemeklerin gündelik yaşam ile turizm sistemi içerisinde varlığını korumasını gerektirmektedir. Kadınlar bu sürecin temel aktörlerinden biridir. Birçok toplumda geleneksel yemeklerin hazırlanması, saklama ve işleme yöntemleri ile tariflerin kuşaklar arasında aktarılması büyük ölçüde kadınların bilgi ve deneyimleri üzerinden gerçekleşmektedir; bu nedenle kadınların yerel mutfak içerisindeki rolü yalnızca üretim emeğiyle sınırlandırılamaz (Sabbah vd., 2024). Kadın kooperatifleri söz konusu bilgi ve becerilerin ekonomik ve toplumsal açıdan daha görünür hâle gelmesine katkı sağlayabilmektedir. Kooperatifler, kolektif örgütlenme ve öz-istihdam olanakları yoluyla kadınların ekonomik güvenliğini ve girişimci davranışlarını destekleyebilmektedir (Datta & Gailey, 2012). Yerel gastronomik ürünler bakımından üretim ve pazarlama faaliyetlerinin kooperatif modeli altında örgütlenmesi ise standartlara uygun üretimin sürdürülmesine ve pazar erişiminin güçlendirilmesine katkı sağlayabilir (Hoşcan, 2018; Iakovidou, 2002).

Bastida vd. (2020), İspanya örneğinden hareketle kooperatiflerin kadın girişimciliğini geliştirme ve girişimcilikteki toplumsal cinsiyet eşitsizliklerinin azaltılmasına katkı sağlama potansiyelini vurgulamaktadır. Bununla birlikte kooperatif modelinin kadınların ekonomik güçlenmesine katkısının kurumsal yapı, yönetim ve karar süreçlerine gerçek katılım gibi koşullara bağlı olduğu görülmektedir.

Yunanistan'da gerçekleştirilen çalışmalar kadın kooperatiflerinin yerel ürünler ve turizm açısından önemini ortaya koymaktadır. Iakovidou (2002), kadın agroturizm kooperatiflerinin kırsal alanlarda kadınlara ekonomik faaliyet alanı açmasının yanında geleneksel ürünlerin tanıtımına katkı sağladığını göstermektedir. Vakoufaris vd. (2007) ise Kuzey Ege'deki kadın kooperatiflerinin geleneksel bilgi ve yerel hammaddelerden yararlanarak bölgesel kalkınmaya destek sunduğunu belirtmektedir.

Türkiye'de de kadın kooperatifleri yerel gastronomik ürünlerin üretimi ve turizme kazandırılması bakımından giderek daha görünür hâle gelmektedir. Cihangir vd. (2023) tarafından Niğde Denee Kadın Kooperatifi üzerine gerçekleştirilen araştırmada kooperatif üyelerinin yöresel gastronomik ürünlerin turizm kapsamında değerlendirilmesine olumlu yaklaştıkları belirlenmiştir. Akmeşe vd. (2024) de Bor Kadın Tarımsal Kalkınma Kooperatifi örneğinde kadın kooperatiflerinin yerel gastronomik ürünlerin sürdürülebilirliğine katkı sağlama potansiyeline dikkat çekmektedir.

Kadın kooperatifleri yerel gastronomik ürünlerin yalnızca üretiminde değil, tanıtımında ve turistik deneyime dönüştürülmesinde de rol oynayabilir. Kooperatif restoranları, üretim atölyeleri, yöresel ürün satış noktaları, gastronomi festivalleri ve üretici pazarları kadın emeğiyle üretilen yerel ürünlerin tüketicilerle doğrudan buluşmasına imkân sağlamaktadır. Yönet Eren'in (2024) Kapadokya'daki kadın kooperatifi restoranları üzerine gerçekleştirdiği araştırma, turistlerin yöresel yemeklerin özgünlüğüne ve kalitesine olumlu yaklaştığını göstermektedir.

Bununla birlikte kadın kooperatiflerinin faaliyetlerinde çeşitli sorunlar bulunmaktadır. Şahankaya Adar vd. (2023), Türkiye'deki kadın kooperatiflerinin kadınların ekonomik güçlenmesine katkı sağlayabilecek önemli yapılar olduğunu ancak kooperatif sayısındaki artışın doğrudan sürdürülebilir istihdam ve gelir anlamına gelmediğini belirtmektedir. Yönetim becerileri, finansal kaynaklara erişim, pazarlama, markalaşma ve profesyonelleşme gibi alanlardaki sınırlılıklar kooperatiflerin sürdürülebilirliğini etkileyebilmektedir.

Bu bağlamda, yerel gastronominin korunması açısından coğrafi işaretler ile kadın kooperatifleri arasında daha güçlü bir ilişki kurulması önem taşımaktadır. Coğrafi işaret ürünün geleneksel ve coğrafi kimliğini korurken kadın kooperatifleri bu ürünün üretiminin sürdürülmesine, geleneksel bilginin aktarılmasına, pazarlanmasına ve turizm aracılığıyla görünür hâle gelmesine katkı sağlayabilir.

YÖNTEM

Bu çalışma, nitel araştırma yaklaşımı çerçevesinde yapılandırılmış kavramsal bir araştırma olup literatür incelemesi (literature review) yöntemine dayanmaktadır. Bütünleştirici literatür incelemesi, belirli bir araştırma problemiyle ilişkili farklı kuramsal ve ampirik çalışmaların birlikte değerlendirilmesine, mevcut bilgi birikiminin sentezlenmesine ve araştırma alanındaki temel eğilimler ile boşlukların ortaya konulmasına olanak sağlayan bir inceleme yöntemidir (Snyder, 2019; Whittemore & Knafl, 2005). Bu yöntemin tercih edilmesinin temel nedeni, yerel mutfakların sürdürülebilirliği, coğrafi işaretler ve kadın kooperatifleri arasındaki ilişkinin farklı disiplinlerde ele alınmış olması ve söz konusu çalışmaların bütüncül bir gastronomi perspektifi altında değerlendirilmesine duyulan gereksinimdir. Araştırmanın verileri kamuya açık ve yayımlanmış akademik çalışmalardan oluşmaktadır. Bu nedenle çalışma, ikincil kaynaklara dayalı kavramsal bir literatür araştırması niteliğindedir. İnceleme sonucunda ulaşılan bulgular, yerel mutfağın sürdürülebilirliği açısından coğrafi işaretler ve kadın kooperatifleri arasındaki ilişkinin açıklanması; akademik çıkarımların geliştirilmesi; sektör uygulayıcıları ve kamu kurumlarına yönelik önerilerin oluşturulması ve gelecekte yapılabilecek ampirik araştırmalara ilişkin araştırma alanlarının belirlenmesi amacıyla sentezlenmiştir.

SONUÇ ve ÖNERİLER

Bu çalışma, yerel mutfağın sürdürülebilirliğinde kadın kooperatiflerinin rolünü coğrafi işaretler bağlamında değerlendirmiştir. Literatürden elde edilen temel sonuç, coğrafi işaret tescilinin yerel gastronomik mirasın korunması açısından önemli ancak tek başına yeterli olmadığıdır. Bir ürünün coğrafi işaretle tescil edilmesi, ürünün adını ve belirli üretim özelliklerini koruma altına alırken üretimin devamlılığı, geleneksel bilginin aktarılması, üreticilerin ekonomik sürdürülebilirliği ve ürünün tüketiciler tarafından tercih edilmesi başka kurumsal ve ekonomik mekanizmaları gerektirmektedir (Belletti vd., 2017; Bowen, 2010).

Kadın kooperatifleri bu bağlamda yerel gastronominin sürdürülebilirliği açısından önemli aktörlerdir. Kadınların geleneksel mutfak bilgisi, üretim deneyimi ve yerel ürünlere ilişkin birikimlerinin kooperatif örgütlenmesi aracılığıyla ekonomik faaliyetlere dönüştürülmesi, hem kültürel mirasın korunmasına hem de kadınların ekonomik güçlenmesine katkı sağlayabilir (Bastida vd., 2020; Cihangir vd., 2023).

Akademik Çıktılar

Çalışmanın temel akademik katkısı, coğrafi işaret literatürü ile kadın kooperatifleri ve yerel mutfak literatürünü ortak bir sürdürülebilirlik çerçevesinde ele almasıdır. Bu çalışma kapsamında incelenen literatürde coğrafi işaretlerin çoğunlukla ürün koruması, tüketici davranışı veya destinasyon pazarlaması; kadın kooperatiflerinin ise kadın girişimciliği, istihdam ve kırsal kalkınma açısından ele alındığı görülmektedir.

Bu çalışma ise coğrafi işaret ile kadın kooperatifi arasındaki ilişkinin yerel gastronomik mirasın sürdürülebilirliği bakımından önem taşıdığını ileri sürmektedir. Özellikle kadınların yerel mutfak bilgisinin taşıyıcısı olmasının coğrafi işaret politikaları açısından daha fazla dikkate alınması gerektiği düşünülmektedir (Sabbah vd., 2024).

Sektör Uygulayıcılarına Yönelik Öneriler

- Öncelikle coğrafi işaretli ürünlerin üretiminde faaliyet gösteren kadın kooperatiflerine ürün standartları, hijyen, gıda güvenliği, paketleme ve markalaşma alanlarında eğitim verilmelidir.
- Kadın kooperatifleri yalnızca küçük ölçekli üretim ve yerel pazar satışıyla sınırlandırılmamalıdır. Oteller, restoranlar, seyahat acenteleri, gastronomi işletmeleri ve turizm organizasyonlarıyla doğrudan iş birlikleri geliştirilmelidir.
- Yerel yönetimler ve destinasyon yönetim kuruluşları, kadın kooperatiflerini gastronomi festivallerine, yöresel ürün pazarlarına ve turistik rotalara sistematik biçimde dâhil etmelidir.
- Coğrafi işaretli ürünlerin ambalaj ve tanıtım materyallerinde ürünün yöresel özelliklerinin yanında kadın üreticilerin ve kooperatiflerin rolünü açıklayan hikâyeleştirme uygulamalarından yararlanılabilir.
- Kadın kooperatiflerinin dijital pazarlama ve e-ticaret kapasiteleri geliştirilmelidir. Böylece yerel gastronomik ürünlerin yalnızca destinasyonu ziyaret eden turistlere değil daha geniş tüketici kitlelerine ulaştırılması mümkün olabilir.
- Bununla birlikte kadın kooperatiflerinin yalnızca kamu hibelerine bağımlı yapılar hâline gelmesinden kaçınılmalıdır. Finansal yönetim, ürün geliştirme, marka yönetimi, fiyatlandırma ve profesyonel işletmecilik konularında sürdürülebilir kapasite geliştirme politikaları uygulanmalıdır.

Gelecek Araştırmalara Yönelik Öneriler

- Gelecek araştırmalarda coğrafi işaretli ürünlerin üretiminde faaliyet gösteren kadın kooperatifleri ile coğrafi işaret tescili bulunmayan yöresel ürünleri üreten kadın kooperatiflerinin karşılaştırılması önerilebilir.
- Kadın kooperatiflerinin yerel mutfak kültürünün korunması üzerindeki etkisi nitel araştırmalarla incelenebilir. Özellikle geleneksel tariflerin, üretim tekniklerinin ve yerel gastronomik bilginin kuşaklar arası aktarımında kooperatiflerin rolü etnografik yöntemlerle araştırılabilir.
- Tüketicilerin “kadın kooperatifi tarafından üretilmiş” ve “coğrafi işaretli” ürünlere yönelik güven, özgünlük algısı, satın alma niyeti ve daha fazla ödeme istekliliği deneysel veya nicel araştırma yöntemleriyle karşılaştırılabilir.
- Ayrıca kadın kooperatiflerinin gastronomi turizmine katkısı turist perspektifinden araştırılabilir. Kooperatif restoranları, üretim atölyeleri ve yerel ürün satış noktalarında yaşanan deneyimlerin destinasyon memnuniyeti, özgünlük algısı ve yeniden ziyaret niyeti üzerindeki etkileri incelenebilir.

Sonuç olarak, yerel mutfağın sürdürülebilirliği açısından temel mesele yalnızca ürünlerin tescil edilmesi değildir. Tescilli veya tescil potansiyeli taşıyan gastronomik ürünleri üreten yerel toplulukların ve özellikle kadınların bu sürece etkin biçimde katılması gerekmektedir. Kadın kooperatifleri, geleneksel mutfak bilgisinin korunması ile ekonomik ve turistik değere dönüştürülmesi arasında önemli bir bağlantı oluşturabilir. Bu nedenle coğrafi işaret, kadın kooperatifçiliği, yerel gastronomi ve turizm politikalarının birbirini tamamlayan bir anlayışla yürütülmesi yerel mutfakların uzun dönemli sürdürülebilirliği açısından önem taşımaktadır.

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FEMALE ADMINISTRATORS IN HIGHER EDUCATION AND SPECIALIZED CONTEXTS: NAVIGATING PROFESSIONALIZATION AND ADMINISTRATIVE COMPLEXITY

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ABSTRACT

Higher education and specialized high schools in Vietnam face unique workforce management challenges due to the specialized nature of academic work, the need for both teaching and research competence, and the increasing demands for industry engagement and practical training. This qualitative study explores workforce management challenges experienced by female administrators across four diverse institutional contexts: (1) a public health sciences university, (2) a traditional medicine department within a public university, (3) a private technology university, and (4) a private high school within a corporate education ecosystem. Through reflective professional practice analysis, the study identifies five major themes: (1) the "double scarcity" of highly qualified professionals, (2) the "invisibility" of administrative work, (3) digital transformation and data management challenges, (4) professional development and retention difficulties, and (5) succession planning and leadership development gaps. The findings reveal that administrators navigate complex institutional environments characterized by competing demands, resource constraints, and stakeholder expectations while managing specialized workforces with diverse professional identities and career aspirations. The study proposes a comprehensive strategic framework addressing both common and context-specific challenges, offering practical recommendations for educational leaders, policymakers, and practitioners across Vietnamese higher education and specialized contexts.

Keywords: higher education; specialized contexts; female administrators; workforce management; professionalization; administrative complexity; digital transformation; Vietnam; reflective practice

1. INTRODUCTION

1.1 Background

Workforce management in Vietnamese higher education and specialized contexts has become increasingly complex as institutions undergo fundamental transformation. The move toward institutional autonomy, the growth of private education, and the increasing demands for quality assurance, research productivity, and industry engagement have created new challenges for administrators. These transformations are occurring within a broader context of Vietnam's higher education reform agenda, which emphasizes internationalization, quality improvement, and institutional accountability (Tran et al., 2019; Nguyen & Nguyen, 2021).

This study focuses on four diverse institutional contexts in Vietnam: a public health sciences university (University H), a traditional medicine department within a public university (Department I), a private technology university (University J), and a private high school within a corporate education ecosystem (School K). These contexts represent different institutional types, governance structures, and professional requirements.

University H is a public health sciences university that has been granted self-governance authority, making it the first health sciences university in Vietnam to operate under this mechanism. This self-governance status provides greater autonomy in workforce management decisions but also imposes greater accountability for institutional performance and financial sustainability. Department I is a specialized department within a public university, focusing on traditional medicine education. As a specialized unit within a larger institution, it faces unique challenges related to resource allocation, recognition, and coordination with other academic units.

University J is a private technology university within a corporate education ecosystem. As a private institution, it operates under different governance and funding arrangements than public universities, with greater flexibility in workforce policies but also greater pressure to demonstrate market relevance and financial viability. School K is a private high school within the same corporate ecosystem. As a relatively new institution, it faces challenges related to establishing institutional identity, developing workforce capacity, and building stakeholder confidence.

Across these contexts, female administrators—department heads, office directors, and administrative officers—manage specialized workforces, coordinate stakeholder relationships, and navigate complex institutional environments. Their experiences provide valuable insights into workforce management challenges and effective responses in diverse educational settings.

1.2 Research Rationale

The rationale for this study is grounded in several observations about workforce management research and practice in Vietnamese higher education and specialized contexts.

First, the diversity of institutional types creates different workforce management challenges requiring context-specific solutions. Public universities face different challenges than private universities; specialized departments face different challenges than comprehensive universities; and institutions within corporate education ecosystems face different challenges than standalone institutions. Understanding these differences is essential for developing appropriate workforce management strategies.

Second, the specialized nature of workforce in these contexts creates unique challenges. Health sciences require faculty who are both academically qualified and clinically experienced. Traditional medicine requires faculty with specialized expertise in traditional knowledge combined with understanding of modern medical approaches. Physical education requires faculty with both teaching and coaching competencies. These specialized requirements create recruitment, development, and retention challenges that general workforce management frameworks may not fully address.

Third, female administrators in these contexts possess valuable experiential knowledge about managing specialized workforces, navigating institutional complexity, and coordinating stakeholder relationships. Their perspectives are particularly important given the underrepresentation of women in senior leadership positions in Vietnamese higher education and the gendered nature of administrative work (Nguyen, 2020; Pham & Tran, 2021).

Fourth, the Vietnamese higher education context is undergoing rapid change, with implications for workforce management. Policy reforms, demographic shifts, technological developments, and changing societal expectations create both challenges and opportunities for administrators. Understanding workforce management challenges and strategies in this dynamic context can inform policy and practice.

1.3 Research Questions

This study aimed to answer the following research questions:

1. What are the workforce management challenges experienced by female administrators in higher education and specialized contexts, and how do institutional type and governance structure influence these challenges?

2. What strategies do female administrators employ to address workforce management challenges, and how do they navigate the tension between academic ideals and operational realities?

3. What future improvements do administrators envision for workforce management, and what strategic framework can be developed to address both common and context-specific challenges?

1.4 Research Objectives

General Objective

The primary objective of this study was to explore workforce management challenges experienced by female administrators across diverse higher education and specialized contexts and to identify both common patterns and context-specific approaches.

Specific Objectives

1. To identify and analyze workforce management challenges across diverse higher education and specialized contexts, examining how institutional type and governance structure shape these challenges.

2. To examine the strategies employed by female administrators to address workforce management challenges, including how they navigate tensions between academic ideals and operational realities.

3. To develop a comprehensive strategic framework that addresses both common and context-specific workforce management challenges in higher education and specialized contexts.

1.5 Significance of the Study

Theoretical Significance

This study contributes to workforce management theory in higher education by examining how institutional type and governance structure shape workforce challenges and responses. It extends existing frameworks by recognizing the diversity of institutional contexts and the need for context-sensitive approaches to workforce management. The study also contributes to understanding of the gendered nature of administrative work and the particular challenges faced by female administrators in specialized educational contexts.

Practical Significance

The findings provide practical guidance for educational leaders managing workforce development in diverse higher education and specialized contexts. The strategic framework developed in this study offers administrators a comprehensive approach to addressing workforce management challenges, with attention to both common patterns across contexts and unique challenges in particular institutional settings.

Policy Significance

The study provides evidence that can inform policy development regarding higher education workforce management. The findings highlight the need for policies that recognize the diversity of institutional contexts, support specialized workforce development, and address the particular challenges faced by female administrators.

2. LITERATURE REVIEW

2.1 Workforce Management in Higher Education

Workforce management in higher education encompasses recruitment, selection, placement, professional development, performance management, motivation, and retention of academic and administrative personnel (Armstrong & Taylor, 2023; Dessler, 2020). Higher education institutions face particular challenges due to the specialized nature of academic work, the need for both teaching and research competence, and the increasing demands for industry engagement (Bush, 2020; Khan & Khan, 2019).

The higher education workforce is characterized by multiple professional identities and career pathways. Faculty members may identify primarily as researchers, teachers, clinicians, or some combination thereof. Administrative professionals may have backgrounds in education, business, or other fields. This diversity of professional identities creates challenges for workforce management, as different groups may have different expectations, motivations, and needs (Boxall & Purcell, 2022).

In Vietnam, higher education workforce management has been shaped by historical, cultural, and policy factors. The transition from a centrally planned to a market-oriented economy has created new opportunities and challenges for higher education institutions (Hayden & Lam, 2017). The introduction of institutional autonomy policies has given institutions greater flexibility in workforce management but also increased accountability and competition (Nguyen & Nguyen, 2021).

2.2 Specialized Workforces in Health Sciences and Traditional Medicine

Specialized workforces, such as those in health sciences and traditional medicine, require specific workforce management approaches. These workforces require professionals who combine academic qualifications with clinical experience, specialized expertise, and ongoing professional development.

Health Sciences Education

Health sciences education requires faculty who are simultaneously academically qualified (PhD level) and clinically experienced. The combination of these qualifications is rare, creating "double scarcity" in the workforce. Health sciences faculty must also maintain clinical competence through ongoing practice and professional development, adding to the complexity of workforce management (Frenk et al., 2010; Boelen & Woollard, 2015).

The health sciences workforce is also characterized by strong professional identity and external professional commitments. Faculty members may maintain clinical practices in addition to their academic responsibilities, creating potential tensions between institutional and professional obligations (Barnes et al., 2020).

Traditional Medicine Education

Traditional medicine education requires faculty with specialized expertise in traditional medical knowledge and practices, combined with understanding of modern medical approaches. This specialized expertise is rare and often transmitted through apprenticeship and experiential learning, making it difficult to develop through formal education programs (Patwardhan & Warude, 2016; Guo et al., 2019).

Traditional medicine education in Vietnam has been shaped by historical and cultural factors, including the integration of traditional and modern medical systems. The preservation and development of traditional medicine knowledge requires workforce strategies that recognize the unique characteristics of this field (Mai & Le, 2018).

2.3 The "Invisibility" of Administrative Work

Administrative work in higher education is often less visible than academic work, yet it is essential for institutional functioning. Research suggests that administrative contributions may not be fully recognized in evaluation and reward systems (Bolman & Deal, 2017; Birnbaum, 1988).

Administrative work in higher education encompasses a wide range of activities, including planning, coordination, communication, problem-solving, decision-making, and relationship management. These activities often occur behind the scenes and may not be captured in traditional performance metrics. The "invisibility" of administrative work has implications for workforce management, including recruitment, development, evaluation, and retention of administrative professionals (Gornall & Bryson, 2014).

The gender dimension of administrative invisibility is particularly significant. Women are overrepresented in administrative roles in higher education, yet administrative work is often undervalued and undercompensated compared to academic work (Morley, 2013; O'Connor, 2015). This gender dimension has implications for workforce equity and the professionalization of administrative work.

2.4 Digital Transformation in Higher Education

Digital transformation in higher education requires significant investment in infrastructure, workforce development, and organizational change. Research suggests that effective digital transformation requires integrated systems, staff competence, and organizational commitment (Fullan, 2020; OECD, 2019; Christensen et al., 2020).

Digital transformation presents both challenges and opportunities for workforce management. On one hand, digital technologies can improve efficiency, enhance communication, and enable new forms of teaching, learning, and administration. On the other hand, digital transformation requires significant investment, workforce development, and organizational change (Pedro et al., 2019).

In the Vietnamese context, digital transformation in higher education has been a policy priority, with investments in infrastructure, capacity building, and system development. However, challenges remain, including infrastructure limitations, workforce readiness, and organizational resistance to change (Nguyen et al., 2020; Tran & Nguyen, 2021).

2.5 Professional Development and Retention

Professional development is essential for maintaining workforce competence and motivation in higher education. Research suggests that access to professional development is associated with job satisfaction, commitment, and retention (Day & Sachs, 2004; OECD, 2019).

Professional development in higher education encompasses a wide range of activities, including formal education, workshops, conferences, mentoring, and job-embedded learning. Effective professional development is aligned with institutional needs and individual career aspirations, is sustained over time, and provides opportunities for reflection and practice (Borko, 2004; Darling-Hammond et al., 2017).

Retention is a significant challenge in higher education, particularly in specialized fields where there is competition from other employers. Retention strategies must address both material factors (compensation, benefits, working conditions) and non-material factors (job satisfaction, organizational culture, career development) (Allen et al., 2010; Marchington & Wilkinson, 2016).

2.6 Succession Planning and Leadership Development

Succession planning is essential for maintaining institutional effectiveness and continuity in higher education. Research suggests that effective succession planning involves systematic identification and development of future leaders, rather than reactive responses to vacancies (Conger & Fulmer, 2003; Rothwell, 2010).

Leadership development in higher education encompasses a wide range of activities, including formal programs, mentoring, coaching, and experiential learning. Effective leadership development addresses the specific competencies required for leadership roles in higher education, including strategic thinking, financial management, stakeholder engagement, and change management (Black et al., 2016; Bolden et al., 2012).

In the Vietnamese context, leadership development in higher education has been a policy priority, with investments in programs for emerging and current leaders. However, challenges remain, including limited resources, competing priorities, and the need for context-specific approaches (Tran et al., 2019; Nguyen & Nguyen, 2021).

2.7 Theoretical Framework

This study is guided by four theoretical perspectives:

Institutional Theory explains how organizations are shaped by their institutional environments, including regulatory, normative, and cultural-cognitive elements (Scott, 2014). This perspective helps explain how institutional type and governance structure shape workforce management practices and challenges.

Strategic Human Resource Management emphasizes alignment between workforce practices and institutional objectives (Boxall & Purcell, 2022). This perspective helps explain how workforce management strategies are shaped by institutional goals, resources, and constraints.

Stakeholder Theory explains how organizations must manage relationships with multiple stakeholders, including faculty, students, employers, and regulators (Freeman, 1984). This perspective helps explain the complexity of workforce management in higher education, where administrators must balance competing stakeholder demands.

Reflective Practice Theory emphasizes the importance of practitioners' reflective thinking about their professional experiences (Schön, 1983). This perspective provides the methodological foundation for the study, emphasizing the value of reflective accounts for understanding professional practice.

3. RESEARCH METHODOLOGY

3.1 Research Design

This study adopted a qualitative research design based on *reflective professional practice and thematic analysis*. The approach was chosen because the study aims to understand participants' experiences, perceptions, and interpretations of workforce management challenges across diverse higher education and specialized contexts.

Reflective professional practice as a research approach allows practitioners to systematically examine their professional experiences, identify patterns and challenges, and articulate strategies and solutions. This approach is particularly suited to understanding the complex, contextual nature of educational administration (Schön, 1983; Brookfield, 2017). Reflective practice enables practitioners to move beyond tacit knowledge to explicit understanding, making their expertise accessible for research and learning (Schön, 1983; Farrell, 2015).

As the instructor and research assistants for the course "Management and Development of Human Resources in Education," we synthesized and analyzed the reflective reports submitted by four master's students. The analysis presented in this paper is derived from their professional experiences and reflective accounts of workforce management in their respective higher education and specialized contexts. This approach builds upon the established tradition of using reflective practice as both a professional development tool and a research methodology in educational administration (Osterman & Kottkamp, 2015).

3.2 Research Context

The study was conducted across four diverse institutional contexts in Can Tho City, Vietnam:

Institution	Type	Key Characteristics
University H	Public Health Sciences	Self-governance, clinical training, research focus
Department I	Traditional Medicine	Specialized, resource constraints, autonomy
University J	Private Technology	Corporate ecosystem, technology focus, competition
School K	Private High School	Corporate ecosystem, new, multi-level

These institutions were selected because they represent diverse higher education and specialized contexts with distinct workforce management characteristics. The selection was purposive, aiming to capture a range of institutional types including public universities, specialized departments, and private institutions within corporate education ecosystems. This diversity enables comparison and contrast of workforce management challenges across different institutional settings (Yin, 2018).

3.3 Participants

Participants comprised four postgraduate students selected in Educational Management at Can Tho University during the school year 2025-2026. All participants were experienced female administrators with direct involvement in workforce management in their respective institutions. The selection criteria included:

1. Current employment in a higher education or specialized high school administrative role
2. Direct responsibility for workforce management functions
3. Willingness to participate in the research
4. Completion of reflective professional reports as part of their MA program

Participant	Institution	Professional Role	Key Responsibilities
P001	University H	Administrator	Faculty development, quality assurance, workload management
P002	Department I	Administrator	Academic coordination, research support, stakeholder relations
P003	University J	Administrator	Industry relations, student placement, coordination
P004	School K	Administrator	Personnel management, strategic planning

The participants' extensive experience in their respective institutions ensures the richness and authenticity of the reflective accounts analyzed in this study.

3.4 Data Collection

Data were collected from reflective professional reports written by participants as part of their Master's program requirements. The reports focused on workforce management challenges and solutions in their respective institutions. The reports were structured to address:

1. Description of the institutional context and workforce characteristics
2. Identification of workforce management challenges
3. Analysis of challenges and their causes
4. Description of strategies employed to address challenges
5. Recommendations for improvement

The reports were submitted as part of the course requirements for the module "*Management and Development of Human Resources in Education*." The assignment structure guided participants to provide comprehensive, well-organized accounts of their workforce management experiences and insights.

Data Collection Process

The data collection process followed these steps:

1. Participants wrote reflective professional reports based on their workplace experiences
2. Reports were submitted for academic assessment
3. Consent was obtained to use the reports for research purposes
4. All identifying information was anonymized

5. Reports were analyzed thematically

The systematic process ensured consistency and transparency in data collection while protecting participant confidentiality.

3.5 Data Analysis

Data were analyzed using Braun and Clarke's (2006) six-phase thematic analysis framework:

1. **Familiarization with data**: Reading and re-reading the reflective reports to gain a holistic understanding of the content. This phase involved multiple readings of each report, with attention to key ideas and emerging patterns.

2. **Generating initial codes**: Identifying relevant segments of text and assigning codes to capture their meaning. This phase involved systematic coding of all reports, with attention to both manifest and latent content.

3. **Searching for themes**: Organizing codes into potential themes. This phase involved grouping related codes and identifying patterns across the data set.

4. **Reviewing themes**: Checking themes against the data to ensure they accurately represent participants' experiences. This phase involved going back to the original data to verify the fit between themes and evidence.

5. **Defining and naming themes**: Refining the themes to clearly articulate their meaning and scope. This phase involved developing clear definitions and descriptions of each theme.

6. **Producing the report**: Writing up the analysis with representative quotes. This phase involved constructing a coherent narrative that presents the findings in relation to the research questions.

As the synthesizing author, I conducted the thematic analysis collaboratively with the research team, with regular meetings to discuss coding decisions and theme development. Disagreements were resolved through discussion until consensus was reached. The collaborative approach enhanced the trustworthiness of the analysis by bringing multiple perspectives to interpretation (Lincoln & Guba, 1985).

3.6 Trustworthiness

Trustworthiness was ensured through multiple strategies:

Credibility: Rich description of contexts and direct quotes from participants provide evidence for the findings. The credibility of the analysis is enhanced by the detailed accounts provided by participants and the use of participants' own language to illustrate themes.

Dependability: Clear documentation of the research process enables others to understand and potentially replicate the study. The systematic approach to data collection and analysis ensures consistency and transparency.

Confirmability: Use of direct quotes to support findings demonstrates the link between data and interpretation. The inclusion of participants' own words ensures that the analysis remains grounded in their experiences.

Transferability: Detailed contextual information allows readers to assess applicability to other contexts. The rich description of institutional contexts enables readers to determine the relevance of findings to their own settings.

Member checking was conducted by sharing preliminary findings with participants to verify accuracy and interpretation. Participants confirmed that the themes accurately reflected their experiences, enhancing the credibility of the findings (Lincoln & Guba, 1985).

3.7 Ethical Considerations

Ethical principles were followed throughout the research:

1. **Informed consent** was obtained from participants

2. Participants were informed that their reports might be used for academic research
3. **Personal identifying information** was removed from the analysis
4. Participants were given the opportunity to **review findings**
5. The research was conducted in accordance with **academic research ethics standards**

The ethical approach ensured that participants' rights and wellbeing were protected throughout the research process.

3.8 MA Requirement Agreements

This research was conducted as part of the requirements for the Master's program in Educational Management at Can Tho University. Through this research, the participants have demonstrated competencies in:

- Analyzing workforce management challenges across different institutional contexts
- Applying theoretical frameworks to practical problems
- Designing qualitative research with multiple cases
- Critically reflecting on professional practice
- Contributing to knowledge in the field of educational management

4. FINDINGS

4.1 Overview of Findings

Thematic analysis of the four reflective reports identified five major themes:

1. **The "Double Scarcity"** of highly qualified professionals
2. **The "Invisibility"** of administrative work
3. **Digital Transformation and Data Management** Challenges
4. **Professional Development and Retention** Difficulties
5. **Succession Planning and Leadership Development** Gaps

These themes capture both common challenges across institutions and context-specific variations. Each theme is discussed below with representative quotes from participants.

4.2 Theme 1: The "Double Scarcity" of Highly Qualified Professionals

The first major theme concerned the "double scarcity" of highly qualified professionals. Participants across institutions described challenges in recruiting and retaining professionals who possess the combination of qualifications and experience required for specialized work.

The Health Sciences Challenge

A participant from University H (P001) described the challenge of recruiting health sciences faculty:

"*In health sciences, we need faculty who are simultaneously academically qualified (PhD level) and clinically experienced. This combination is rare. When we find such talent, we struggle to retain them against private sector offers. Our young, newly-minted PhDs are the most vulnerable to poaching—they have the qualifications and the flexibility. We need better retention strategies."*

The participant further explained how self-governance status, while providing greater autonomy, does not fully address this challenge:

"*Self-governance gives us more flexibility in recruitment and compensation, but we still operate within public sector salary frameworks. The private sector can offer salaries two or three times higher. We must find other ways to attract and retain talent—professional development opportunities, research support, or the prestige of academic work*."

The challenge of double scarcity is compounded by the high cost of faculty development in health sciences. As P001 explained:

"Developing a health sciences faculty member from PhD completion to clinical competence requires significant investment—time, resources, and mentorship. When they leave, we lose not just the individual but the investment we have made in their development."

The Traditional Medicine Challenge

A participant from Department I (P002) described the challenge of recruiting traditional medicine faculty:

"*Traditional medicine requires faculty with specialized expertise in traditional medical knowledge and practices, combined with understanding of modern medical approaches. This specialized expertise is rare and difficult to develop. There are few programs that train traditional medicine educators, and those who have the expertise often prefer clinical practice to academic work."*

The participant highlighted the generational dimension of the challenge:

"*Senior traditional medicine practitioners hold valuable knowledge but are approaching retirement. Younger practitioners have formal academic qualifications but may lack the depth of traditional knowledge. We need to bridge this gap through mentoring and knowledge transfer, but this takes time and institutional commitment*."

Competition with Private Sector

The competition with private sector employers was a recurring concern across institutions. P001 described the impact:

"The private sector offers compensation packages we cannot match. Our young, newly-minted PhDs are the most vulnerable to poaching—they have the qualifications and the flexibility. We need better retention strategies."

The private sector competition is particularly intense in technology fields. P003 described the challenge at University J:

"*In technology fields, the private sector competition is intense. Our faculty can earn three to four times more in industry. We try to compete by offering flexibility, research opportunities, and the satisfaction of teaching, but these are not always enough."*

4.3 Theme 2: The "Invisibility" of Administrative Work

The second major theme concerned the "invisibility" of administrative work. Participants described how much of their work is not visible to others, not recognized in evaluation systems, and not valued as it should be.

Coordination Work

A participant from University J (P003) described coordination work:

"Managing internships involves significant coordination work—matching students with companies, negotiating placements, following up with both parties, troubleshooting issues. Much of this work is invisible and not recognized in traditional evaluation systems. When internships run smoothly, people assume it is easy. When problems arise, the coordinator is blamed."

The participant described how the invisible nature of coordination work affects job satisfaction and recognition:

"*The coordination work is demanding and time-consuming, but it does not fit easily into performance metrics. How do you measure successful negotiation? How do you quantify problem prevention? This makes it difficult to demonstrate the value of our work."*

Emotional Labor

P003 further described the emotional labor involved in administrative work:

"*We must constantly manage student expectations, address concerns, and support students through difficult decisions. This emotional labor is part of our work but is rarely acknowledged or valued. It can be draining, especially when we are dealing with difficult situations or conflict.*"

The emotional labor is particularly intense in student-facing administrative roles. As P003 explained:

"*Students come to us with high hopes and sometimes unrealistic expectations. When things do not go as planned—a placement falls through, a company is not a good fit—we must manage their disappointment and find alternatives. This requires emotional skill and resilience.*"

Evaluation Gaps

A participant from University H (P001) described evaluation gaps:

"*Administrative contributions—such as improving processes, building relationships, or supporting colleagues—may not be captured in traditional evaluation systems, which focus on readily quantifiable metrics. This creates a disconnect between what we actually do and what is valued.*"

The participant described how the evaluation gap affects career advancement:

"*When promotion decisions are based on publications and teaching evaluations, administrative contributions may not be recognized. This can discourage talented professionals from pursuing administrative careers or staying in administrative positions.*"

Workload and Recognition

P004 described the workload-recognition gap at School K:

"*Administrative work is demanding and requires a wide range of skills—planning, problem-solving, communication, negotiation. Yet it often is not recognized at the same level as academic work. This can be demoralizing.*"

The participant described the impact of workload on retention:

"The workload is heavy, and the recognition is limited. People may feel overwhelmed and undervalued. This contributes to turnover and makes it difficult to attract talented people to administrative roles."

4.4 Theme 3: Digital Transformation and Data Management Challenges

The third major theme concerned digital transformation and data management challenges. Participants described significant challenges in implementing digital systems and managing data effectively.

Data Fragmentation

A participant from University J (P003) described data fragmentation:

"Data is stored across multiple systems—Google Workspace, LMS, and various departmental systems. When we need to update information, we must manually adjust several spreadsheets. This is inefficient and increases the risk of errors."

The participant described the impact of data fragmentation on decision-making:

"*When data is fragmented, it is difficult to get a comprehensive picture. We may not have the information we need to make strategic decisions or identify problems early. This limits our ability to be proactive rather than reactive.*"

The data management challenges at University J are particularly acute due to the integration of academic and corporate systems within the education ecosystem. As P003 explained:

"*We need to connect academic data with industry data—student placements, company feedback, employment outcomes. The systems do not talk to each other easily, so we must do a lot of manual work.*"

Infrastructure Limitations

A participant from Department I (P002) described infrastructure limitations:

"*We need better technology infrastructure—reliable internet, up-to-date hardware, integrated systems. Without adequate infrastructure, digital transformation efforts are limited. We cannot implement the systems we need when the basic infrastructure is not in place."*

The participant described how infrastructure limitations affect daily operations:

"*Staff spend significant time on manual data management and troubleshooting technology issues. This reduces the time available for more strategic work. We need investment in infrastructure to improve efficiency*."

Digital Competence

P002 also described challenges related to digital competence:

"*Digital transformation requires not just technology but also workforce competence. Staff need training and support to use new systems effectively. This requires investment in professional development that is often not prioritized."*

The participant described the generational dimension of digital competence:

"Younger staff are often comfortable with technology, but more senior staff may need more training and support. This creates challenges for change management—how to bring everyone along."

Cost and Sustainability

P003 described the cost and sustainability challenges of digital transformation:

"*Digital transformation requires significant investment—software, hardware, training, ongoing support. For private institutions like University J, this investment must be justified in terms of return. Demonstrating the return on investment can be challenging."*

The participant described the sustainability challenge:

"*Systems need ongoing maintenance and updates. Staff need ongoing training. The investment does not stop with implementation. Institutions must plan for the full lifecycle of technology investments."*

4.5 Theme 4: Professional Development and Retention Difficulties

The fourth major theme concerned professional development and retention difficulties. Participants described challenges in providing adequate professional development and retaining talented staff.

Professional Development Access

A participant from University H (P001) described professional development challenges:

"*The need for professional development is significant, yet administrative professionals often have less access to development opportunities than faculty. This limits their career growth and institutional effectiveness."*

The participant described how limited access to professional development affects administrative professionals:

"*When administrative professionals see that their colleagues in academic roles have more development opportunities, it can affect morale and retention. They may feel that their contributions are not valued or that their career growth is limited."*

Retention Challenges

A participant from School K (P004) described retention challenges:

"*As a new school, we face significant retention challenges. Staff may feel overwhelmed by the workload or uncertain about the future. We need to develop retention strategies that address both material and non-material needs."*

The participant described the impact of institutional newness on retention:

"*New institutions face unique challenges—lack of established systems, high expectations from stakeholders, and uncertainty about the future. Staff may feel that they are taking on more risk than they would in an established institution.*"

Career Pathways

P002 described challenges related to career pathways:

"*For administrative professionals, career pathways may not be as clear as for academic professionals. This can make it difficult to plan for the future and may affect retention.*"

The participant described the need for clearer career pathways:

"*We need more explicit career pathways for administrative professionals—what opportunities are available, what competencies are required, what support is available. This would help professionals plan their careers and stay motivated.*"

Material and Non-Material Factors

P004 described the combination of material and non-material factors affecting retention:

"*Retention is influenced by both material factors—salary, benefits, working conditions—and non-material factors—recognition, job satisfaction, organizational culture. We need to address both to retain talented staff.*"

The participant described the particular importance of non-material factors in education:

"*Education is not a highly paid field. We cannot compete with private sector salaries. We must offer other things—meaningful work, supportive culture, professional growth, work-life balance. These factors are important for retention.*"

4.6 Theme 5: Succession Planning and Leadership Development Gaps

The fifth major theme concerned succession planning and leadership development gaps. Participants described challenges in systematically developing future leaders and planning for leadership transitions.

Systematic Planning

A participant from University H (P001) described planning gaps:

"We are good at identifying immediate needs but less systematic in developing future leaders. Succession planning is often reactive rather than proactive. When a key leader leaves, we scramble to find a replacement."

The participant described the impact of reactive planning:

"*Reactive planning means we may not have qualified candidates ready when positions become vacant. This can create instability and disrupt institutional effectiveness. We need to be more systematic.*"

Leadership Development Opportunities

A participant from Department I (P002) described development limitations:

"*We need more opportunities for leadership development—programs that build management skills, strategic thinking, and change management competence. These opportunities are often limited.*"

The participant described how limited development opportunities affect the leadership pipeline:

"If we do not develop future leaders, we will have a limited pool of candidates when leadership positions become vacant. This can limit our institutional capacity and effectiveness."

Bottlenecks and Constraints

P003 described bottlenecks in the leadership pipeline:

"*There are often bottlenecks in leadership pipelines—limited positions, limited opportunities for advancement, limited support for development. Talented professionals may leave for opportunities elsewhere."*

The participant described the impact of constraints on women's leadership:

"*Women face particular constraints in leadership pipelines—less access to networks, less access to mentors, less recognition of potential. We need to be intentional about supporting women's leadership development*."

Gender Dimension

P004 described the gender dimension of succession planning:

"*In our context, women are well-represented in administrative positions but less represented in senior leadership. There is a gap between middle-level and senior-level leadership that needs to be addressed."*

The participant described strategies to address the gender gap:

"*We need to be intentional about identifying and developing women for leadership roles. This requires addressing barriers, providing support, and creating opportunities for visibility and growth."*

5. DISCUSSION

5.1 Introduction

This section discusses the findings in relation to previous research and theoretical perspectives. The study explored workforce management challenges across diverse higher education and specialized contexts through reflective professional practice. The discussion addresses each of the three research questions in turn, considering the implications for theory, practice, and policy.

5.2 Discussion of Major Findings

5.2.1 Workforce Management Challenges and Institutional Influences

The first research question asked: ***What are the workforce management challenges experienced by female administrators in higher education and specialized contexts, and how do institutional type and governance structure influence these challenges*?**

The findings identified five major workforce management challenges: (1) the "double scarcity" of highly qualified professionals, (2) the "invisibility" of administrative work, (3) digital transformation and data management challenges, (4) professional development and retention difficulties, and (5) succession planning and leadership development gaps. These challenges were common across institutional contexts, with variations shaped by institutional type and governance structure.

Common Challenges

The five themes identified in this study reflect workforce management challenges that are common across higher education contexts globally. The "double scarcity" of highly qualified professionals is a well-documented challenge in specialized fields such as health sciences and technology (Frenk et al., 2010; Barnes et al., 2020). The "invisibility" of administrative work has been identified in research on higher education administration (Bolman & Deal, 2017; Gornall & Bryson, 2014). Digital transformation challenges have been documented in research on technology adoption in education (Fullan, 2020; OECD, 2019). Professional development and retention difficulties are common in higher education (Day & Sachs, 2004; Allen et al., 2010). Succession planning and leadership development gaps have been identified in research on leadership in higher education (Conger & Fulmer, 2003; Black et al., 2016).

The commonality of these challenges suggests that workforce management in higher education and specialized contexts faces similar issues regardless of institutional type. This finding supports the application of established workforce management frameworks while recognizing the need for context-specific adaptations.

Institutional Variations

The findings also revealed variations in workforce challenges shaped by institutional type and governance structure:

Public vs. Private Institutions: Public institutions (University H, Department I) faced challenges related to public sector salary frameworks and resource constraints. Private institutions (University J, School K) faced challenges related to market competition and the need to demonstrate return on investment. These variations reflect the different governance structures and resource environments of public and private institutions (Bush, 2020; Boxall & Purcell, 2022).

Comprehensive vs. Specialized Institutions: Specialized institutions (University H, Department I) faced particular challenges related to specialized workforce requirements and professional identity. Comprehensive institutions face different challenges related to managing diverse professional groups. These variations reflect the different professional profiles of specialized and comprehensive institutions (Scott, 2014).

New vs. Established Institutions: New institutions (School K) faced challenges related to institutional identity, system development, and stakeholder confidence. Established institutions (University H, Department I) faced different challenges related to institutional change and adaptation. These variations reflect the different life cycle stages of institutions (Schein, 2010).

The variations in challenges across institutional contexts support the institutional theory perspective, which emphasizes how organizations are shaped by their institutional environments (Scott, 2014). The findings suggest that workforce management strategies must be sensitive to institutional context.

5.2.2 Strategies and Navigating Tensions

The second research question asked: **What strategies do female administrators employ to address workforce management challenges, and how do they navigate the tension between academic ideals and operational realities?**

Strategies Employed

Participants described strategies to address each major challenge:

For the "double scarcity" of highly qualified professionals:

- Offering non-salary benefits such as professional development, research support, and academic prestige
- Developing talent internally through mentoring and training programs
- Creating flexible work arrangements to accommodate professional and personal needs
- Building partnerships with industry to access talent and resources

For the "invisibility" of administrative work:

- Documenting administrative contributions for evaluation purposes
- Advocating for recognition of administrative work in institutional policies
- Building relationships with academic colleagues to demonstrate value
- Creating networks of administrative professionals for mutual support and advocacy

For digital transformation and data management challenges:

- Implementing integrated systems to reduce fragmentation
- Providing training and support for staff digital competence
- Advocating for infrastructure investment
- Using data for decision-making while recognizing limitations

For professional development and retention difficulties:

- Offering professional development opportunities to administrative staff
- Creating clear career pathways for administrative professionals
- Addressing both material and non-material factors affecting retention
- Building a positive organizational culture

For succession planning and leadership development gaps:

- Identifying and developing future leaders systematically
- Creating mentorship and coaching programs
- Providing leadership development opportunities
- Addressing gender barriers to leadership

These strategies reflect the strategic human resource management perspective, which emphasizes alignment between workforce practices and institutional objectives (Boxall & Purcell, 2022). The strategies also reflect the stakeholder theory perspective, which recognizes the need to manage relationships with multiple stakeholders (Freeman, 1984).

Navigating Tensions

Participants described navigating tensions between academic ideals and operational realities:

Research vs. Clinical Practice: In health sciences, administrators navigated the tension between research productivity and clinical practice. Faculty are expected to produce research while maintaining clinical competence. Administrators must balance these competing expectations while ensuring faculty wellbeing and institutional effectiveness.

Quality vs. Quantity: In traditional medicine, administrators navigated the tension between maintaining quality and meeting demand. There is a need to train more practitioners while ensuring deep knowledge of traditional medicine. Administrators must balance these competing objectives while managing resource constraints.

Excellence vs. Equity: In private education, administrators navigated the tension between pursuing excellence and ensuring equity. There is pressure to demonstrate market leadership while remaining accessible to diverse learners. Administrators must balance these competing values while maintaining institutional sustainability.

Autonomy vs. Accountability: In public institutions, administrators navigated the tension between autonomy and accountability. Self-governance provides greater flexibility but also greater accountability for outcomes. Administrators must balance the benefits of autonomy with the requirements of accountability.

These tensions reflect the complexity of workforce management in higher education and specialized contexts. Administrators must navigate competing demands while maintaining institutional effectiveness and supporting workforce development.

5.2.3 Future Improvements and Strategic Framework

The third research question asked: ***What future improvements do administrators envision for workforce management, and what strategic framework can be developed to address both common and context-specific challenges*?**

Future Improvements

Participants envisioned improvements in several areas:

Recognition of Administrative Work: Participants envisioned evaluation systems that recognize the complexity and contributions of administrative work. This includes capturing administrative contributions in performance metrics and valuing them in promotion decisions.

Integrated Digital Systems: Participants envisioned integrated data management systems that reduce manual work and improve efficiency. This includes systems that connect academic and administrative data and support strategic decision-making.

Professional Development Access: Participants envisioned ensuring administrative professionals have access to professional development opportunities comparable to those available to faculty. This includes formal programs, mentoring, and job-embedded learning.

Succession Planning: Participants envisioned systematic succession planning and leadership development programs that identify and develop future leaders. This includes addressing gender barriers and creating clear career pathways.

Work-Life Balance: Participants envisioned work environments that support work-life balance, including flexible work arrangements and supportive organizational culture.

Competitive Compensation: Participants envisioned compensation that is competitive with other employers, including private sector and international institutions.

Strategic Framework

Based on the findings, the study proposes a comprehensive strategic framework for workforce management in higher education and specialized contexts. The framework addresses both common and context-specific challenges through integrated strategies at three levels:

1. Institutional Level

Vision and Strategy: Develop a clear vision for workforce development aligned with institutional mission and strategy. This includes defining workforce needs, setting goals, and allocating resources.

Governance and Policies: Establish governance structures and policies that support effective workforce management. This includes policies for recruitment, development, evaluation, and retention.

Culture and Values: Build organizational culture that values and supports workforce development. This includes recognizing contributions, fostering inclusion, and promoting wellbeing.

2. Operational Level

Recruitment and Selection: Develop effective recruitment and selection processes that attract qualified candidates. This includes targeting diverse talent pools, using evidence-based selection methods, and building employer brand.

Professional Development: Provide professional development opportunities that build workforce competence and support career growth. This includes formal programs, mentoring, coaching, and job-embedded learning.

Performance Management: Implement performance management systems that recognize contributions and support development. This includes clear expectations, regular feedback, and fair evaluation.

Retention and Succession: Develop retention strategies and succession plans that maintain workforce stability. This includes addressing material and non-material factors affecting retention and systematically developing future leaders.

3. Individual Level

Career Development: Support individual career development through clear pathways, mentoring, and opportunities for growth. This includes helping staff identify career goals and develop plans to achieve them.

Wellbeing and Support: Address workforce wellbeing through supportive work environments and access to resources. This includes work-life balance, recognition, and emotional support.

Engagement and Motivation: Foster engagement and motivation through meaningful work, recognition, and opportunities for contribution. This includes involving staff in decision-making and valuing their input.

Context-Specific Adaptations

The strategic framework recognizes the need for context-specific adaptations:

Public Institutions: Focus on strategies that address public sector constraints while leveraging autonomy. This includes developing talent internally, building partnerships, and advocating for policy changes.

Private Institutions: Focus on strategies that balance market competitiveness with educational mission. This includes competitive compensation, innovation, and stakeholder engagement.

Specialized Institutions: Focus on strategies that address specialized workforce requirements. This includes developing specialized expertise, maintaining professional networks, and building partnerships with practice settings.

New Institutions: Focus on strategies that build institutional identity and workforce capacity. This includes developing systems, building culture, and establishing stakeholder confidence.

5.3 Theoretical Implications

The findings have several implications for workforce management theory in higher education and specialized contexts.

Firstly, the findings extend institutional theory by showing how different institutional environments shape workforce management challenges and responses. The variations across institutional types—public vs. private, comprehensive vs. specialized, established vs. new—demonstrate the importance of context in understanding workforce management.

Secondly, the findings extend strategic human resource management theory by showing how alignment between workforce practices and institutional objectives must account for the diversity of institutional contexts. The findings suggest that strategic alignment must be adapted to different institutional types and governance structures.

Thirdly, the findings extend stakeholder theory by showing how workforce management in higher education must manage multiple stakeholder relationships. The tensions described by participants—research vs. clinical practice, quality vs. quantity, excellence vs. equity, autonomy vs. accountability—reflect the complexity of stakeholder management in higher education.

Fourthly, the findings extend reflective practice theory by demonstrating the value of reflective accounts for understanding professional practice. The reflective reports provided rich insights into workforce management challenges and strategies that would not be accessible through other methods.

5.4 Practical Implications

The findings have several practical implications for educational leaders, administrators, and practitioners.

Recognition of Administrative Work

Institutions should develop evaluation systems that recognize the complexity and contributions of administrative work. This includes capturing administrative contributions in performance metrics, valuing them in promotion decisions, and providing appropriate compensation and recognition.

Integrated Digital Systems

Institutions should invest in integrated data management systems that reduce manual work and improve efficiency. This includes systems that connect academic and administrative data, support strategic decision-making, and reduce errors.

Professional Development Access

Institutions should ensure administrative professionals have access to professional development opportunities comparable to those available to faculty. This includes formal programs, mentoring, and job-embedded learning.

Succession Planning

Institutions should develop systematic succession planning and leadership development programs. This includes identifying and developing future leaders, addressing gender barriers, and creating clear career pathways.

Addressing Material and Non-Material Factors

Institutions should address both material and non-material factors affecting retention. This includes compensation, working conditions, recognition, job satisfaction, and organizational culture.

Gender-Sensitive Strategies

Institutions should develop gender-sensitive workforce management strategies that address the particular challenges faced by female administrators. This includes addressing gender barriers in leadership development, ensuring equitable access to opportunities, and creating supportive work environments.

5.5 Policy Implications

The findings have several implications for higher education policy in Vietnam.

Recognition of Institutional Diversity

Policies should recognize the diversity of institutional contexts and allow for context-specific approaches. Uniform policies may not be appropriate for different institutional types, governance structures, or specialization areas.

Support for Specialized Workforce Development

Policies should support specialized workforce development in fields such as health sciences and traditional medicine. This includes funding for faculty development programs, clinical training, and traditional medicine education.

Professional Development Investment

Policies should invest in professional development for administrative professionals, recognizing their essential role in institutional functioning. This includes funding for training programs, leadership development, and career pathways.

Digital Transformation Support

Policies should support digital transformation in higher education through infrastructure investment, capacity building, and system development. This includes funding for technology, training, and integration.

Gender Equity in Leadership

Policies should promote gender equity in higher education leadership, addressing barriers to women's advancement and supporting women's leadership development.

Workforce Planning

Policies should support systematic workforce planning, including succession planning and talent development. This includes funding for leadership development programs and support for career pathways.

5.6 Limitations and Future Research

This study has several limitations that should be acknowledged. *First of all*, the study is based on a small number of participants (four) from specific institutional contexts. While the small number allows for in-depth analysis, the findings may not be generalizable to other contexts. Future research could include larger samples and additional institutional types.

Secondly, the study is based on reflective reports written for academic purposes. While the reports provide rich accounts of participants' experiences, they may be shaped by academic expectations and

the assignment structure. Future research could use multiple data collection methods, including interviews, observations, and document analysis.

Thirdly, the study focuses on female administrators. While this focus is important for understanding gender dimensions of administrative work, future research could include male administrators for comparative analysis.

Fourthly, the study is cross-sectional, capturing participants' experiences at a single point in time. Future research could use longitudinal designs to examine how workforce management challenges and strategies evolve over time.

And *fifth,* the study is conducted in the Vietnamese context. While the findings have implications for other contexts, future research could examine workforce management in other national and institutional contexts.

5.7 Conclusion

This study explored workforce management challenges experienced by female administrators across diverse higher education and specialized contexts. The findings identified five major themes: the "double scarcity" of highly qualified professionals, the "invisibility" of administrative work, digital transformation and data management challenges, professional development and retention difficulties, and succession planning and leadership development gaps.

The paper demonstrates that higher education institutions face unique workforce management challenges due to specialized workforces, institutional complexity, and competitive labor markets. Understanding these challenges and developing appropriate responses is essential for maintaining institutional effectiveness and supporting workforce development.

The proposed strategic framework offers a comprehensive approach to addressing both common and context-specific challenges. The framework addresses workforce management at three levels—institutional, operational, and individual—and recognizes the need for adaptations to different institutional types and governance structures.

The findings have implications for theory, practice, and policy. They extend workforce management theory by showing how institutional type and governance structure shape workforce challenges. They provide practical guidance for educational leaders managing workforce development in diverse contexts. They offer evidence to inform policy development regarding higher education workforce management.

As higher education continues to undergo transformation, workforce management will remain a critical concern for administrators, policymakers, and practitioners. The findings of this study contribute to understanding workforce management challenges and effective responses in diverse higher education and specialized contexts.

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FEMALE ADMINISTRATORS IN SPECIALIZED EDUCATIONAL CONTEXTS: NAVIGATING PROFESSIONALIZATION AND INSTITUTIONAL CHALLENGES

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ABSTRACT

Specialized educational contexts in Vietnam face unique workforce management challenges due to the diverse nature of their operations, ranging from early childhood education to specialized training centers and schools in varying socioeconomic conditions. This qualitative study explores workforce management challenges experienced by female administrators across four diverse specialized educational contexts: (1) a preschool, (2) a mathematics thinking center, (3) a high school in a challenging socioeconomic area, and (4) an economic training and research center. Through reflective professional practice analysis, the study identifies five major themes: (1) workforce competency gaps in specialized teaching contexts, (2) resource constraints and institutional adaptation challenges, (3) generational and stakeholder expectation tensions, (4) digital transformation and technological adaptation difficulties, and (5) professional development and retention challenges. The findings reveal that administrators navigate complex institutional environments characterized by diverse stakeholder expectations, resource limitations, and the need for specialized pedagogical expertise. The study proposes a comprehensive strategic framework addressing both common and context-specific challenges, offering practical recommendations for educational leaders, policymakers, and practitioners across specialized Vietnamese educational settings.

Keywords: specialized education; female administrators; workforce management; preschool education; mathematics thinking centers; reflective practice; institutional challenges; Vietnam; educational leadership

1. INTRODUCTION

1.1 Background

Specialized educational contexts in Vietnam encompass a diverse range of institutions beyond traditional public schools, including early childhood education centers, specialized training centers, and schools operating in challenging socioeconomic conditions. These institutions face unique workforce management challenges due to their specialized missions, diverse stakeholder expectations, and varying resource constraints.

This study focuses on four diverse specialized educational contexts: a preschool (School L), a mathematics thinking center (School M), a high school in a challenging socioeconomic area (School N), and an economic training and research center (School O). These contexts represent different institutional types, operational characteristics, and workforce management challenges.

School L is a public preschool established in 2015, serving 337 children across 12 classes with 33 staff members. The school faces challenges in workforce planning, professional development, and teacher motivation in the context of early childhood education reform.

School M is a private mathematics thinking center serving over 100 students aged 4–12 years, with 12 full-time and part-time teachers and 3 administrative staff. The center specializes in abacus mental arithmetic and cognitive development programs, facing challenges in teacher standardization, curriculum protection, and resource utilization.

School N is a public high school located in a challenging socioeconomic area, characterized by high competition from private schools, high parental expectations, and significant pressure for educational quality and digital transformation.

School O is an economic training and research center, facing challenges in workforce planning, professional development, and resource management in a competitive training market.

Despite increased attention to educational reform in Vietnam, limited research has examined the specific workforce management challenges experienced by female administrators across these diverse specialized educational contexts. Understanding these challenges is essential for developing appropriate policies, practices, and support systems.

1.2 Research Rationale

The rationale for this study is grounded in several observations about workforce management research and practice in specialized educational contexts.

First, the diversity of specialized educational contexts creates different workforce management challenges requiring context-specific solutions. Preschools face challenges in early childhood education reform, while mathematics thinking centers face challenges in curriculum standardization and teacher training. Schools in challenging socioeconomic areas face challenges in resource constraints and teacher retention, while training centers face challenges in market competition and workforce professionalization.

Second, the specialized nature of workforce in these contexts creates unique challenges. Early childhood education requires teachers with specialized pedagogical skills and knowledge of child development. Mathematics thinking centers require teachers with expertise in cognitive development and specialized teaching methods. Schools in challenging areas require teachers who can address diverse student needs with limited resources.

Third, female administrators in these contexts possess valuable experiential knowledge about managing specialized workforces, navigating institutional complexity, and coordinating stakeholder relationships. Their reflective accounts provide rich data for understanding the interplay between institutional type, workforce practices, and adaptive strategies.

1.3 Research Questions

This study aimed to answer the following research questions:

1. What are the common workforce management challenges and adaptive strategies experienced by female administrators across diverse specialized educational contexts in Vietnam?

2. How do institutional characteristics—including type (preschool, specialized center, secondary school, training center), resource availability, and stakeholder expectations—shape workforce management practices and responses?

3. What strategic approaches can be developed to enhance workforce effectiveness, professional development, and institutional sustainability in specialized educational settings?

1.4 Research Objectives

General Objective

The primary objective of this study was to explore workforce management challenges experienced by female administrators across diverse specialized educational contexts and to develop a comprehensive strategic framework for addressing both common and context-specific challenges.

Specific Objectives

1. To identify and analyze workforce competency gaps, resource constraints, and stakeholder-related tensions that create challenges for female administrators in specialized educational institutions.

2. To examine how institutional type, operational characteristics, and the digital transformation context influence workforce management approaches and administrative decision-making.

3. To propose evidence-based strategies and policy recommendations for strengthening workforce professionalization, retention, and institutional adaptation in specialized educational contexts.

1.5 Significance of the Study

Theoretical Significance

This study contributes to workforce management theory by examining how institutional type and operational characteristics shape workforce challenges and responses in specialized educational contexts. It extends institutional theory and strategic human resource management by applying them to the under-researched domain of specialized educational institutions in Vietnam.

Practical Significance

The findings provide practical guidance for educational leaders managing workforce development in diverse specialized educational settings. The proposed strategic framework offers actionable recommendations tailored to different institutional types.

Policy Significance

2. LITERATURE REVIEW

2.1 Workforce Management in Specialized Educational Contexts

Workforce management in specialized educational contexts encompasses recruitment, selection, placement, professional development, performance management, motivation, and retention of educational personnel (Armstrong & Taylor, 2023; Dessler, 2020). Specialized institutions face particular challenges due to their unique missions, specialized pedagogical requirements, and diverse stakeholder expectations (Bush, 2020).

Early Childhood Education

Early childhood education has gained increasing attention in Vietnam through the implementation of national standards and professional development requirements (Circular No 28/2026/TT-BGDĐT). Preschools face challenges in workforce planning, professional development, and teacher motivation (Tran Kim Dung, 2018).

Specialized Training Centers

Mathematics thinking centers require teachers with specialized pedagogical expertise in cognitive development and mathematics education. These centers face challenges in teacher recruitment, training, and retention (Dang Quoc Bao, 2018).

Challenging Socioeconomic Contexts

Schools in challenging socioeconomic areas face unique workforce management challenges, including teacher retention, motivation, and professional development within resource constraints (Tran Kiem, 2021).

2.2 Specialized Pedagogical Requirements

Specialized educational contexts require teachers with specific pedagogical competencies. Research suggests that effective professional development must be aligned with the specialized requirements of different educational contexts (Darling-Hammond et al., 2017; Guskey, 2002).

Early Childhood Pedagogy

Early childhood teachers require knowledge of child development, play-based learning, and child-centered approaches. Professional development must address these specialized competencies.

Mathematics Thinking Pedagogy

Mathematics thinking centers require teachers with expertise in cognitive development, abacus mental arithmetic, and specialized teaching methods. Teacher training must address these specialized requirements.

2.3 Resource Constraints and Institutional Adaptation

Resource constraints affect workforce management in specialized educational contexts. Research suggests that effective workforce management requires strategic allocation of limited resources, creative approaches to professional development, and stakeholder engagement (Freeman, 1984; Scott, 2014).

2.4 Digital Transformation in Education

Digital transformation presents both opportunities and challenges for specialized educational institutions. Fullan (2020) emphasizes that successful digital transformation requires not only technological infrastructure but also mindset shifts, professional development, and aligned organizational culture. Fragmented technology adoption can create inefficiencies and increase administrative burdens.

2.5 Theoretical Framework

This study is guided by four theoretical perspectives that collectively inform the research questions and analytical approach:

Theory	Key Proponents	Relevance to This Study
Institutional Theory	Scott (2014)	Explains how organizations are shaped by institutional environments, governance structures, professional norms, and resource constraints—directly addressing RQ2 (institutional influences).
Strategic Human Resource Management	Boxall & Purcell (2022)	Emphasizes alignment between workforce practices and institutional objectives—informs RQ1 (challenges and strategies) and RQ3 (strategic approaches).
Stakeholder Theory	Freeman (1984)	Explains how organizations must manage relationships with multiple stakeholders (parents, teachers, regulators) to achieve objectives—addresses stakeholder tensions in RQ1 and RQ2.
Reflective Practice Theory	Schön (1983)	Emphasizes practitioners' reflective thinking about professional experiences—provides the epistemological basis for the qualitative methodology and data collection.

The integration of these theories allows the study to examine workforce management challenges at multiple levels: institutional (macro), organizational (meso), and individual practitioner (micro). This multi-level lens ensures that the findings address the complexity inherent in specialized educational contexts.

3. RESEARCH METHODOLOGY

3.1 Research Design

This study adopted a qualitative research design based on *reflective professional practice and thematic analysis*. The approach was chosen because the study aims to understand participants' experiences, perceptions, and interpretations of workforce management challenges across diverse specialized educational contexts.

Reflective professional practice as a research approach allows practitioners to systematically examine their professional experiences, identify patterns and challenges, and articulate strategies and solutions. This approach is particularly suited to understanding the complex, contextual nature of educational administration (Schön, 1983).

As the instructor and the research assistants for the course "*Management and Development of Human Resources in Education"*, we synthesized and analyzed the reflective reports submitted by four master's students. The analysis presented in this paper is derived from their professional experiences and reflective accounts of workforce management in their respective specialized educational contexts.

3.2 Research Context

The study was conducted in the context of four diverse specialized educational institutions in Vietnam's Mekong Delta region:

Institution	Type	Location	Key Characteristics
School L	Public Preschool	Dong Thap Province	Established 2015, 337 children, 12 classes, 33 staff
School M	Private Math Center	Can Tho City	100+ students aged 4–12, 12 teachers, 3 admin staff
School N	Public High School	Vinh Long Province	Challenging socioeconomic area, high expectations
School O	Training Center	Can ThoCity	Economic training, research, and consulting

These institutions were selected because they represent diverse specialized educational contexts with distinct workforce management characteristics.

3.3 Participants

Participants comprised four postgraduate students in Educational Management at Can Tho University in the school year of 2025–2026. All of the participants were experienced female administrators with direct involvement in workforce management in their respective institutions.

Participant	Institution	Professional Role	Key Responsibilities
P001	School L	Administrator	Workforce planning, professional development, teacher motivation
P002	School M	Administrator	Teacher recruitment, training, curriculum standardization

Participant	Institution	Professional Role	Key Responsibilities
P003	School N	Administrator	Personnel management, quality assurance, stakeholder relations
P004	School O	Administrator	Workforce professionalization, training program management

3.4 Data Collection

Data were collected from reflective professional reports written by participants as part of their Master's program requirements. The reports focused on workforce management challenges and solutions in their respective institutions.

Data Collection Process:

1. Participants wrote reflective professional reports based on their workplace experiences.
2. Reports were submitted for academic assessment.
3. Consent was obtained to use the reports for research purposes.
4. All identifying information was anonymized.
5. Reports were analyzed thematically.

3.5 Data Analysis

Data were analyzed using Braun and Clarke's (2006) six-phase thematic analysis framework:

1. **Familiarization with data:** Reading and re-reading the reflective reports.
2. **Generating initial codes:** Identifying relevant segments of text.
3. **Searching for themes:** Organizing codes into potential themes.
4. **Reviewing themes:** Checking themes against the data.
5. **Defining and naming themes:** Refining the themes.
6. **Producing the report:** Writing up the analysis.

As the synthesizing authors, we conducted the thematic analysis collaboratively with a research colleague, with regular meetings to discuss coding decisions and theme development. Disagreements were resolved through discussion until consensus was reached.

3.6 Trustworthiness

Trustworthiness was ensured through:

- **Credibility:** Rich description and direct quotes from participants.
- **Dependability:** Clear documentation of the research process.
- **Confirmability:** Use of direct quotes to ground findings in data.
- **Transferability:** Detailed contextual information to enable readers to assess applicability to other settings.

3.7 Ethical Considerations

Ethical principles were followed throughout the research, including informed consent, anonymity, and the opportunity for participants to review findings.

3.8 Research Question–Findings Alignment Matrix

To ensure analytical rigor and coherence, the findings are mapped directly to the research questions as follows:

Research Question	Corresponding Themes	Key Data Sources
RQ1: Common challenges and adaptive strategies	Theme 1 (Competency Gaps), Theme 3 (Stakeholder Tensions), Theme 5 (Retention)	P001, P002, P003 reports
RQ2: Institutional influences on practices	Theme 2 (Resource Constraints), Theme 4 (Digital Transformation)	All participants (contextual comparisons)
RQ3: Strategic approaches for sustainability	Theme 5 (Professional Development), Cross-theme synthesis	All participants + proposed framework

This matrix guided the discussion section, ensuring that each research question is explicitly addressed.

4. FINDINGS

4.1 Overview of Findings

Thematic analysis of the four reflective reports identified five major themes:

1. Workforce Competency Gaps in specialized teaching contexts
2. Resource Constraints and Institutional Adaptation challenges
3. Generational and Stakeholder Expectation tensions
4. Digital Transformation and Technological Adaptation difficulties
5. Professional Development and Retention challenges

4.2 Theme 1: Workforce Competency Gaps in Specialized Teaching Contexts

The first major theme concerned workforce competency gaps in specialized teaching contexts.

Early Childhood Education

A participant from School L (P001) described the challenge:

"Although our teachers meet the training requirements, their ability to apply technology, innovate educational methods, and adapt to digital transformation varies significantly. This inconsistency affects the quality of education across different classes."

Mathematics Thinking Center

A participant from School M (P002) described the challenge:

"*Mathematics thinking requires a highly interactive pedagogical approach, completely different from traditional mathematics. However, our internal training process is short-term, and new teachers have not truly absorbed the philosophy of developing children's thinking before they begin teaching."*

Specialized Teacher Standardization

P002 further described the challenge of teacher standardization:

"*With 12 teachers (only 4 full-time and 8 part-time), teacher turnover has reached 25% over the past year. This turnover mainly affects part-time teachers (students in Pedagogy/Mathematics), leading to localized staff shortages during peak periods at the beginning of the new school year."*

Analysis in Relation to RQ1

This theme reveals a common challenge across contexts: the gap between formal qualifications and actual specialized teaching competencies. The adaptive strategies employed include short-term internal training, but these are insufficient—pointing to the need for more systematic professional development pathways.

4.3 Theme 2: Resource Constraints and Institutional Adaptation

The second major theme concerned resource constraints and institutional adaptation challenges.

Facility Utilization Challenges

A participant from School M (P002) described facility utilization:

"*Due to the characteristic that students only study outside office hours (evenings on weekdays and all day on Saturdays and Sundays), classrooms are empty 70–80% of the daytime, causing significant waste in rental costs."*

Financial Resource Constraints

A participant from School N (P003) described financial constraints:

"In *a challenging socioeconomic area, financial resources are limited. The school must compete with private and international schools for high-quality teachers. We need flexible financial mechanisms and attractive benefits to retain our best teachers*."

Equipment and Technology Constraints

A participant from School M (P002) described equipment challenges:

"*Mathematics thinking depends heavily on visual learning tools (logic toys, abacus, flashcards). However, inventory management is not strictly controlled weekly/monthly, leading to loss and damage."*

Analysis in Relation to RQ2

This theme highlights institutional type influences: the private center (School M) faces underutilization and rental waste, while the public high school (School N) faces financial competition. Resource constraints shape administrative decision-making differently depending on institutional funding models and operational schedules.

4.4 Theme 3: Generational and Stakeholder Expectation Tensions

The third major theme concerned generational and stakeholder expectation tensions.

Tension Between Teaching and Counseling Teams

A participant from School M (P002) described this tension:

"*The enrollment counseling team faces pressure from KPIs, leading to overpromising to parents, which creates pressure on the teaching team when students who do not match the entrance requirements are admitted."*

High Parental Expectations

A participant from School N (P003) described the challenge:

"Parents in developed economic areas often have high education levels and demand very high quality in teaching, soft skills, and students' integration capabilities. This creates enormous psychological pressure on teachers, easily leading to overload and professional burnout."

Generational Differences in Teaching Staff

A participant from School N (P003) described generational challenges:

"The teaching staff includes many different age groups. Veteran teachers have extensive traditional teaching experience but limitations in technology application, while young teachers can quickly access technology but sometimes lack pedagogical experience."

Analysis in Relation to RQ1 and RQ2

Stakeholder tensions are common across contexts (RQ1) but manifest differently: in the private center, tensions are internal (between departments); in the public school, they are external (parental pressure). Generational differences are particularly pronounced in public schools with long-serving staff, illustrating how institutional history shapes workforce dynamics (RQ2).

4.5 Theme 4: Digital Transformation and Technological Adaptation

The fourth major theme concerned digital transformation and technological adaptation difficulties.

Technology Application Challenges

A participant from School N (P003) described the challenge:

"Although facilities are modern, the requirement for 100% of teachers (especially veteran teachers) to master AI tools, advanced learning management software, and personalized teaching methods is a difficult problem in terms of training and mindset transformation."

Fragmented Technology Use

A participant from School M (P002) described technology fragmentation:

"Attendance tracking and daily student evaluations still use many paper records or separate messaging applications (Zalo/Facebook), not yet integrated into a unified center management system (CRM/LMS), causing difficulties in tracking children's learning progress."

Digital Transformation in Preschool Context

A participant from School L (P001) described the challenge:

"*The school needs to gradually build a unified personnel database, implement electronic records management, and apply software for staff evaluation, training management, and career development tracking. However, technology infrastructure and staff capabilities are still limited."*

Analysis in Relation to RQ2 and RQ3

Digital transformation challenges are shaped by institutional characteristics: public schools face generational resistance, private centers face fragmentation due to limited investment, and preschools face infrastructure gaps. These findings inform strategic approaches (RQ3) such as differentiated training and phased technology adoption.

4.6 Theme 5: Professional Development and Retention Challenges

The fifth major theme concerned professional development and retention challenges.

Professional Development in Preschool

A participant from School L (P001) described the challenge:

"*Professional development activities are still one-size-fits-all, not yet truly connected to individual capacity development needs. Assessment of the effectiveness of training has not focused on practical application, so outcomes are not yet high."*

Teacher Retention in Competitive Markets

A participant from School N (P003) described the challenge:

"Private and international schools are ready to offer attractive salaries to lure good teachers away. This causes 'brain drain' and difficulties in maintaining a team of leading experts at our school."

Work-Life Balance Challenges

A participant from School M (P002) described the challenge:

"*Workload for teachers increases significantly, while compensation is limited, affecting motivation, commitment, and the ability to develop the team's capacity."*

Analysis in Relation to RQ1 and RQ3

Retention challenges are common across all contexts (RQ1), driven by competitive markets and workload-compensation imbalances. The strategic implications (RQ3) include the need for differentiated professional development, competitive compensation packages, and non-material incentives such as career progression opportunities.

5. DISCUSSION

This section discusses the findings in direct response to the three research questions, integrates theoretical perspectives, and proposes a strategic framework.

5.1 Discussion of Research Question 1: Common Challenges and Adaptive Strategies

RQ1: ***What are the common workforce management challenges and adaptive strategies experienced by female administrators across diverse specialized educational contexts in Vietnam?***

The findings reveal several **common challenges** cutting across all four institutional contexts:

1. **Workforce competency gaps** – Administrators consistently reported that teachers lacked specialized pedagogical skills aligned with their institutional missions, whether in early childhood education, mathematics thinking, or general secondary education. This aligns with Darling-Hammond et al. (2017), who emphasize that effective professional development must be context-specific.

2. **Resource constraints** – Financial limitations, facility underutilization, and equipment shortages were reported across all contexts, consistent with institutional theory (Scott, 2014), which posits that resource availability shapes organizational behavior and adaptation.

3. **Stakeholder expectation tensions** – Administrators navigated conflicting demands from parents, teachers, and regulatory bodies. This reflects stakeholder theory (Freeman, 1984), which highlights the challenge of balancing multiple, often competing, stakeholder interests.

4. **Digital transformation difficulties** – Fragmented technology adoption, training gaps, and generational resistance were universal concerns, supporting Fullan's (2020) observation that digital transformation requires cultural and pedagogical shifts, not just infrastructure.

5. **Professional development and retention challenges** – One-size-fits-all training, teacher turnover, and work-life balance issues were common, resonating with Herzberg's (1959) motivation-hygiene theory, which distinguishes between satisfiers (achievement, recognition) and dissatisfiers (salary, working conditions).

Adaptive strategies employed by administrators included:

- Short-term internal training programs.
- Stakeholder communication and expectation management.
- Creative resource utilization (e.g., scheduling optimization).
- Phased technology adoption.
- Non-material retention incentives (recognition, professional growth opportunities).

However, these strategies were often reactive rather than proactive, indicating the need for a more systematic strategic framework.

5.2 Discussion of Research Question 2: Institutional Influences on Practices

RQ2*: How do institutional characteristics—including type, resource availability, and stakeholder expectations—shape workforce management practices and responses?*

The findings demonstrate that **institutional type** significantly shapes workforce management practices:

Institutional Type	Key Influence	Manifestation in Findings
Preschool (School L)	Regulatory environment + reform pressure	Emphasis on professional development aligned with national standards; infrastructure limitations
Private Math Center (School M)	Market competition + operational efficiency	High turnover, facility underutilization, fragmentation of technology, internal departmental tensions
Public High School (School N)	Socioeconomic context + parental expectations	Financial competition, generational divides, high psychological pressure on teachers
Training Center (School O)	Market positioning + professionalization	Workforce professionalization challenges, competitive training market dynamics

Resource availability also shapes practices:

- Public institutions face bureaucratic constraints but have stable funding.
- Private institutions have more flexibility but face financial sustainability pressures.
- Institutions in challenging socioeconomic areas face additional recruitment and retention difficulties.

Stakeholder expectations vary systematically:

- Private centers face pressure from parents as paying customers.
- Public schools face pressure from both parents and regulatory bodies.
- Preschools face pressure from reform requirements and workforce development demands.

These findings extend institutional theory (Scott, 2014) by demonstrating how different institutional logics—regulatory, market, and professional—interact within specialized educational contexts to produce distinct workforce management challenges and responses.

5.3 Discussion of Research Question 3: Strategic Approaches for Sustainability

RQ3: ***What strategic approaches can be developed to enhance workforce effectiveness, professional development, and institutional sustainability in specialized educational settings?***

Based on the findings and theoretical integration, we propose a Comprehensive Strategic Framework for Specialized Educational Workforce Management comprising five pillars:

Pillar 1: Specialized Professional Development Pathways

- Develop context-specific training programs aligned with institutional missions (early childhood pedagogy, mathematics thinking, etc.).
- Move from one-size-fits-all to differentiated professional development based on individual competency assessments.
- Establish partnerships with universities for formal certification and ongoing professional learning.

Pillar 2: Resource Optimization and Financial Sustainability

- Implement facility-sharing models to maximize utilization (e.g., daytime use of private center facilities for other programs).
- Develop diversified funding sources (government subsidies, private investment, fee structures).
- Adopt inventory management systems to reduce waste and loss.

Pillar 3: Stakeholder Engagement and Communication

- Establish regular communication channels with parents to align expectations.
- Create clear role definitions and communication protocols between departments (e.g., counseling vs. teaching teams).
- Develop mechanisms for addressing generational differences through mentorship and cross-generational learning.

Pillar 4: Integrated Digital Transformation

- Adopt unified management systems (CRM/LMS) to replace fragmented paper-based and messaging-app-based processes.
- Provide differentiated technology training for veteran and younger teachers.
- Phase implementation to manage change resistance and capacity constraints.

Pillar 5: Comprehensive Retention and Motivation Strategies

- Develop competitive compensation packages (salary, benefits, performance bonuses).
- Address non-material factors: career progression, recognition, work-life balance, and professional autonomy.
- Create a positive organizational culture that values both veteran expertise and young teachers' innovation.

Strategic Framework Summary Table

Pillar	Key Actions	Target Outcomes
1. Professional Development	Context-specific training, partnerships, competency-based pathways	Enhanced teacher competencies, reduced competency gaps
2. Resource Optimization	Facility sharing, diversified funding, inventory systems	Improved resource utilization, financial sustainability
3. Stakeholder Engagement	Communication channels, role clarity, mentorship	Reduced tensions, aligned expectations
4. Digital Transformation	Integrated systems, differentiated training, phased implementation	Streamlined operations, improved data tracking
5. Retention & Motivation	Competitive compensation, career pathways, positive culture	Reduced turnover, increased commitment

This framework addresses both common and context-specific challenges, providing practical guidance for administrators across diverse specialized educational settings.

6. CONCLUSION

6.1 Summary of Findings

This study explored workforce management challenges experienced by female administrators across diverse specialized educational contexts in Vietnam. Through reflective professional practice analysis of four institutions—a preschool, a mathematics thinking center, a high school in a challenging socioeconomic area, and an economic training and research center—five major themes were identified: (1) workforce competency gaps, (2) resource constraints and institutional adaptation, (3) generational and stakeholder expectation tensions, (4) digital transformation challenges, and (5) professional development and retention difficulties.

6.2 Addressing the Research Questions

RQ1 (Common challenges and strategies): Administrators across all contexts faced competency gaps, resource constraints, stakeholder tensions, digital transformation difficulties, and retention challenges. Adaptive strategies included short-term training, stakeholder communication, creative resource use, and non-material incentives—but these were often reactive and insufficient.

RQ2 (Institutional influences): Institutional type (preschool, private center, public high school, training center) significantly shaped workforce practices through differences in regulatory environments, market pressures, socioeconomic contexts, and stakeholder expectations. Resource availability and generational staff composition further influenced administrative responses.

RQ3 (Strategic approaches): The proposed five-pillar strategic framework—specialized professional development, resource optimization, stakeholder engagement, integrated digital transformation, and comprehensive retention strategies—offers evidence-based guidance for enhancing workforce effectiveness and institutional sustainability.

6.3 Contributions of the Study

Theoretical Contributions:

- Extends institutional theory and strategic HRM to specialized educational contexts in Vietnam.
- Demonstrates the interplay between institutional type, resource constraints, and stakeholder dynamics in shaping workforce management practices.
- Validates reflective practice as a valuable approach for generating actionable knowledge from practitioners' lived experiences.

Practical Contributions:

- Provides a contextualized strategic framework adaptable to different institutional types.
- Offers specific recommendations for workforce planning, professional development, retention, and digital transformation.
- Empowers female administrators with evidence-based strategies for navigating institutional complexities.

Policy Contributions:

- Informs policy development on teacher standards, professional development requirements, and resource allocation for specialized educational institutions.
- Highlights the need for differentiated policies that recognize the diversity of specialized educational contexts.

6.4 Limitations and Future Research

Limitations:

- The study is based on four cases in the Mekong Delta region; findings may not be generalizable to other regions or institutional types.
- Data were drawn from reflective reports; follow-up interviews could provide deeper insights.
- The study focused on female administrators; comparative research with male administrators could reveal gender-specific dynamics.

Future Research Directions:

- Quantitative studies to validate the proposed strategic framework across larger samples.
- Comparative studies across regions (urban vs. rural, different provinces) to examine contextual variations.
- Longitudinal research to track the implementation and effectiveness of strategic workforce interventions.
- Studies exploring the intersection of gender, leadership, and workforce management in specialized educational contexts.

6.5 Final Remarks

Specialized educational contexts in Vietnam face unique and complex workforce management challenges. Female administrators, through their reflective practice and experiential knowledge, navigate these challenges with creativity and resilience. However, sustainable improvements require systematic strategic approaches that address both common and context-specific issues. This study contributes to that goal by providing empirical evidence, theoretical integration, and practical recommendations that can inform educational leaders, policymakers, and practitioners in their ongoing efforts to strengthen workforce effectiveness and institutional quality in Vietnam's diverse specialized educational landscape.

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METABOLIC SYNDROME AND MODERN THERAPEUTIC AND SURGICAL APPROACHES TO ITS MANAGEMENT

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Background. Metabolic syndrome (MetS) is a multifactorial clinical condition characterized by abdominal obesity, arterial hypertension, impaired glucose metabolism, hypertriglyceridemia, and reduced high-density lipoprotein cholesterol. MetS significantly increases the risk of type 2 diabetes mellitus, cardiovascular disease, non-alcoholic fatty liver disease, and other obesity-related complications. Modern management requires an individualized and multidisciplinary strategy combining lifestyle modification, pharmacological therapy, and, in selected patients, metabolic surgery.

The aim of this study to evaluate the clinical effectiveness of conservative and surgical treatment approaches in patients with metabolic syndrome and to assess their impact on metabolic and obesity-related outcomes.

Materials and Methods. A clinical analysis was performed in 66 patients with metabolic syndrome. Patients were evaluated according to body mass index (BMI), arterial blood pressure, fasting glucose, HbA1c, lipid profile, and associated metabolic comorbidities. Conservative treatment included individualized dietary intervention, increased physical activity, weight-management strategies, and pharmacological treatment of hyperglycemia, hypertension, and dyslipidemia. Patients with severe obesity and inadequate metabolic control despite conservative treatment were considered for metabolic surgery, predominantly laparoscopic sleeve gastrectomy.

Results. Patients receiving conservative treatment demonstrated improvement in metabolic parameters following lifestyle modification and pharmacological therapy. However, patients with severe obesity and multiple metabolic complications achieved more pronounced and sustained clinical improvement after surgical treatment. Metabolic surgery was associated with significant reductions in body weight and BMI, improved glycemic control, favorable changes in lipid parameters, and better blood pressure control. A reduction in the need for antidiabetic and antihypertensive medications was also observed, particularly among patients with obesity-associated type 2 diabetes mellitus.

Conclusion. The management of metabolic syndrome should be based on an individualized and multidisciplinary approach. Lifestyle modification and pharmacological therapy remain the cornerstone of initial treatment. However, metabolic surgery represents an effective treatment option for appropriately selected patients with severe obesity and uncontrolled metabolic complications. Our clinical experience with 66 patients supports the integrated use of therapeutic and surgical strategies to improve metabolic outcomes and reduce the long-term cardiovascular risk associated with metabolic syndrome.

Keywords: metabolic syndrome; obesity; metabolic surgery; bariatric surgery; sleeve gastrectomy; type 2 diabetes mellitus; arterial hypertension; dyslipidemia; insulin resistance.

UNIVERSAL HEALTH COVERAGE AND PRIMARY HEALTHCARE STRENGTHENING: PATHWAYS TO EQUITABLE HEALTH SYSTEMS

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ABSTRACT

Universal Health Coverage (UHC) remains central to SDG 3.8, yet over half the global population lacks access to essential health services. In Nigeria and other low- and middle-income countries, weak Primary Healthcare (PHC) systems, high out-of-pocket expenditure, and inequitable financing hinder progress toward UHC. This paper examines how PHC strengthening serves as the primary pathway to UHC and equitable health systems. Anchored on the WHO PHC Framework 2018 and Wagstaff's Framework on UHC and Health Financing Equity, the study adopts a desk review and secondary data analysis of WHO, World Bank, and Federal Ministry of Health reports from 2015-2026. Findings show that countries investing in PHC as the foundation of UHC achieve better health outcomes, lower catastrophic spending, and greater resilience. In Nigeria, only 30% of the population has access to essential services, while out-of-pocket expenditure accounts for over 70% of total health spending. PHC facilities face underfunding, human resource gaps, and weak governance. The paper argues that UHC cannot be achieved through hospital-centric models. Applying the two theoretical lenses, it recommends increased domestic financing, expansion of the Basic Health Care Provision Fund, integration of health insurance, community engagement, and digital health to strengthen PHC and accelerate UHC. Achieving equity in health requires deliberate PHC-led policies aligned with both service delivery and financing principles.

Keywords: Universal Health Coverage, Primary Healthcare, Health Equity, Health Financing, Nigeria, SDG 3

Introduction

Health is a fundamental human right enshrined in the 1948 Universal Declaration of Human Rights and reaffirmed in the Constitution of the World Health Organization, which defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 2023). Beyond being a right, health is also a critical driver of economic growth, social stability, and sustainable development. Healthy populations are more productive, children learn better, and households are less likely to fall into poverty due to medical costs.

In 2015, world leaders adopted the 2030 Agenda for Sustainable Development, with Goal 3 focused on "Ensure healthy lives and promote well-being for all at all ages." Target 3.8 specifically calls for the achievement of Universal Health Coverage (UHC) by 2030: "achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all" (United Nations, 2020). UHC has since become the central organizing principle for health system reform globally. (United Nation, 2020).

UHC means that all individuals and communities receive the full range of quality health services they need, from health promotion and disease prevention to treatment, rehabilitation, and palliative care, without suffering financial hardship (WHO, 2023). It is not about providing a minimum package for the

poor. It is about ensuring equity that the poorest and most marginalized have the same access as the rich. Achieving UHC requires strong, resilient health systems that are people-centered and responsive.

Within this global agenda, Primary Healthcare (PHC) has been reaffirmed as the most inclusive, efficient, and effective strategy for achieving UHC. The 1978 Alma-Ata Declaration first positioned PHC as "the key to achieving Health for All." Forty years later, the 2018 Astana Declaration reaffirmed PHC as the foundation of strong and sustainable health systems (WHO, 2023). The WHO PHC Framework 2018 operationalizes this vision through three interconnected components: 1) integrated health services that meet people's needs throughout the life course, 2) multi sectoral policies and actions that address the broader determinants of health, and 3) empowered people and communities that participate in decision-making. (WHO, 2023).

The evidence supporting PHC is overwhelming. Countries with strong PHC systems have better health outcomes, lower costs, and greater preparedness for health emergencies. Thailand achieved UHC in 2002 by investing in district health systems and community health centers. Rwanda reduced under-five mortality by 75% between 2000 and 2015 largely through its network of community health workers and health posts. These examples show that PHC is not a second-class option for poor countries. It is the smartest investment any country can make.

Despite this global consensus, progress toward UHC remains slow and uneven. According to the WHO and World Bank (2023), at least half of the world's population still lacks access to essential health services, and nearly 2 billion people face catastrophic or impoverishing health spending. In Sub-Saharan Africa, the challenges are most acute. Health systems are fragmented, underfunded, and unable to meet the growing burden of both communicable diseases like malaria, TB, and HIV, and the rising tide of non-communicable diseases such as hypertension, diabetes, and cancer. Out-of-pocket payments remain the dominant mode of health financing, pushing an estimated 100 million people into poverty each year.

The COVID-19 pandemic further exposed the weaknesses of health systems that neglected PHC. Countries with strong PHC networks were better able to conduct testing, contact tracing, vaccination, and community engagement. In contrast, hospital-centric systems were overwhelmed. The pandemic made it clear: without PHC, there can be no health security and no UHC.

In Nigeria, Africa's most populous nation with a projected population of 237.5 million in 2026, the quest for UHC and PHC strengthening is both urgent and complex. Nigeria has made important policy commitments. The National Health Act 2014 established the Basic Health Care Provision Fund (BHCPF) to provide a minimum package of services at PHC level. The National Health Insurance Authority Act 2022 mandates health insurance for all residents. The PHC Revitalization Agenda aims to make at least one functional PHC center available per political ward.

However, the gap between policy and implementation remains wide. According to the World Bank (2025), only 30% of Nigerians have access to essential health services. Out-of-pocket expenditure accounts for over 70% of total health spending, one of the highest rates globally. This means that for most Nigerians, getting sick can mean financial ruin. Less than 5% of the population is covered by any form of health insurance, and coverage is concentrated among formal sector workers in urban areas.

The consequences are visible in health outcomes. Nigeria accounts for 20% of global maternal deaths and 10% of under-five deaths. Maternal mortality is estimated at 512 per 100,000 live births and under-five mortality at 117 per 1,000 live births (WHO, 2023). Life expectancy is 54.6 years, far below the global average of 73.4 years. At the same time, the health system is plagued by inequities. Service coverage in the South-West is 61% compared to 29% in the North-East (World Bank, 2025). Rural areas have fewer health workers, fewer drugs, and poorer infrastructure. (FMOH, 2023).

A major reason for this poor performance is the weak state of PHC. Of the estimated 30,000 PHC facilities in Nigeria, only about 10,000 are considered functional (FMOH, 2023). Most lack basic infrastructure such as reliable power, clean water, and internet. Human resource density is 1.5 health workers per 1,000 populations, well below the WHO threshold of 4.45. Drug stock outs are common, and referral systems between PHC and hospitals are weak. Governance is fragmented across federal, state, and local government levels, leading to duplication and inefficiency.

Financing is another critical constraint. Nigeria's health budget has consistently been below 5% of the national budget, far short of the 15% commitment made by African leaders in the 2001 Abuja Declaration. The BHCPF, though innovative, is underfunded and subject to delays in disbursement. Strategic purchasing and pooling mechanisms are weak. As a result, households bear the brunt of health costs, and the poor are often excluded from care.

Theoretical guidance is available to address these challenges. The WHO PHC Framework provides a roadmap for how services should be organized and delivered. Wagstaff's Framework on UHC and Health Financing Equity explains how services should be paid for to ensure fairness and financial protection. Together, these frameworks suggest that Nigeria cannot achieve UHC by building more tertiary hospitals or running more vertical disease programs. The solution lies in strengthening PHC as the foundation, and reforming health financing to reduce reliance on out-of-pocket payments. (Wagstaff, 2009).

This paper is therefore motivated by the need to examine the pathways through which PHC strengthening can accelerate progress toward UHC and equitable health systems in Nigeria. It asks: What is the current status of PHC and UHC? What are the barriers? What lessons can be learned from countries that have succeeded? And what specific strategies should Nigeria adopt?

In the sections that follow, this paper reviews relevant literature, applies the two theoretical frameworks, analyzes empirical evidence from Nigeria and other countries, and proposes concrete recommendations. The central argument is simple: if Nigeria is serious about UHC and equity, it must put PHC first.

Statement of the Problem

Despite Nigeria's status as Africa's largest economy with a GDP of $377.37 billion in 2026, health outcomes remain poor due to a weak PHC system and inequitable financing. Over 70% of health spending is out-of-pocket, and less than 5% of Nigerians are covered by health insurance (World Bank, 2025). PHC facilities lack drugs, equipment, and staff. Current UHC efforts have focused on tertiary care and vertical programs, neglecting PHC. This has resulted in inequitable access, high catastrophic health expenditure, and poor health outcomes. Without strengthening PHC using both service delivery and financing equity principles, Nigeria will not achieve UHC by 2030.

Objectives of the Study

The broad objective of this study is to examine how PHC strengthening, guided by WHO and Wagstaff's frameworks, can accelerate UHC and health equity in Nigeria.

Specific Objectives:

1. Assess the current state of PHC and UHC in Nigeria.
2. Analyze barriers to PHC and UHC using the two theoretical frameworks.
3. Review global experiences of PHC led UHC.
4. Propose strategies to strengthen PHC for UHC and equity.

Research Questions

1. What is the current status of PHC and UHC in Nigeria?
2. How do service delivery and financing gaps hinder UHC according to WHO and Wagstaff's frameworks?
3. What lessons can Nigeria learn from countries that achieved UHC through PHC?
4. What strategies can strengthen PHC for UHC and equity in Nigeria?

Significance of the Study

This study contributes to policy and academia by linking service delivery and financing theories to UHC. For policymakers, it justifies increased investment in PHC to meet the 15% Abuja Declaration target.

For health managers, it highlights operational gaps in service delivery. For development partners, it aligns interventions with the PHC agenda. For citizens, it advocates for financial protection and equitable access. Ultimately, strengthening PHC will reduce maternal and child deaths and protect households from poverty.

Literature Review

Conceptual Review

Universal Health Coverage: Access to quality health services for all without financial hardship (WHO, 2018).

Primary Healthcare: First level of contact with the health system. Emphasizes accessibility, affordability, community participation (WHO, 2018).

Health Equity: Absence of avoidable differences in health among population groups.

Theoretical Framework

WHO Primary Healthcare Framework 2018

The WHO framework posits that strong PHC is built on 3 pillars:

Integrated health services: People-centered care across the life course, from health promotion to palliative care. Multi sectoral policy and action: Addressing social determinants of health such as water, sanitation, education and nutrition. Empowered people and communities: Participation, social accountability, and community health workers. The theory suggests that UHC is only achievable if health systems are anchored on PHC. In Nigeria, weak performance on all 3 pillars explains poor UHC progress. (WHO, 2018).

Wagstaff's Framework on UHC and Health Financing Equity 2009

Wagstaff (2009) argues that UHC has two dimensions: service coverage and financial protection. Equity in health financing requires that funding based on ability to pay move from out-of-pocket to taxes and compulsory insurance. The poor and vulnerable should have priority access and financial risk should be spread across the population. Countries that rely on out-of-pocket payments, like Nigeria with 70%, fail on equity. The framework recommends prepayment, pooling, and strategic purchasing. This theory complements WHO's by addressing the financing side of PHC strengthening.

Harmonization of the Two Theories:

The WHO framework addresses how services should be delivered, while Wagstaff's addresses how they should be financed. Together they provide a complete pathway: Deliver services through PHC and Finance them equitably which equate UHC and Health Equity.

Empirical Review

Global Evidence: PHC led UHC Success Stories

Thailand "30 Baht Scheme" 2002

Thailand achieved 99% population coverage by combining PHC expansion with universal insurance (WHO, 2018). Before 2002, out-of-pocket was 33%. After reform it dropped to 12%, aligning with Wagstaff's principle. PHC facilities were upgraded and made gatekeepers to the system (WHO PHC pillar 1). Result: Maternal mortality dropped from 44 to 20 per 100,000. Catastrophic health expenditure fell by 50%. (WHO, 2023).

Rwanda - Community-Based Health Insurance 2003-2020

Rwanda increased insurance coverage from 7% to 91% by investing in PHC and Mutuelles (Rwanda Ministry of Health, 2021). They deployed 45,000 community health workers 1 per 500 people, reflecting WHO pillar 3. Financing used prepayment and subsidies for the poor (Wagstaff principle). Under-five mortality dropped from 196 to 50 per 1,000.

Ethiopia - Health Extension Program 2004

Ethiopia trained 40,000 female Health Extension Workers to deliver 16 PHC packages at community level. This aligns with WHO pillars 1 and 3. Child mortality fell 67% between 2000-2016. Government health spending increased from 8% to 12% of budget, reducing out-of-pocket from 37% to 31%. (WHO, 2018).

African Regional Evidence

Ghana - National Health Insurance Scheme 2004

Ghana used tax and NHIS levy to fund PHC. Coverage reached 40% by 2020 (WHO,2023). However, provider payment delays and exclusion of informal sector show Wagstaff principle is partially applied. PHC utilization increased but quality gaps remain.

Kenya - Linda Mama Program 2013

Free maternity services at PHC level increased facility deliveries from 44% to 62% (World Bank, 2025). But high out-of-pocket for drugs and diagnostics shows financing gap. This highlights that service delivery without financing reform is incomplete.

Nigeria -Specific Evidence

Basic Health Care Provision Fund - BHCPF 2018-2024

The BHCPF was created under National Health Act 2014 to provide 1% of Consolidated Revenue for PHC. Uzochukwu et al. (2021) evaluated BHCPF in 6 states and found: drug availability increased from 35% to 68% of PHCs, and ANC attendance rose 22%. However, funding release was delayed by 9-12 months, and only $0.50 per capita was spent vs WHO recommended $86. This shows partial application of both theories.

National Health Insurance Authority - NHIA 2022

Onoka et al. (2020) found only 4% of Nigerians are covered by health insurance, mostly formal sector. 96% of the informal sector and poor are excluded, violating Wagstaff's "use based on need" principle. Out-of-pocket remains 70.5% of total health expenditure (World Bank, 2025).

PHC Revitalization Agenda 2019-2026

Federal Ministry of Health (2023) reported that of 30,000 PHCs, only 10,000 are functional. Human resource density is 1.5 health workers per 1,000 vs WHO threshold of 4.45. 60% of PHCs lack regular power and 45% lack essential drugs. This shows failure of WHO pillar 1.

Impact of COVID-19 and Subsidy Removal

Yusuf et al. (2024) surveyed households in Kaduna, Kano and Lagos post-2023. 78% reduced health seeking due to cost. PHC attendance dropped 15% because transport costs increased. This shows how macroeconomic shocks worsen both service access and financial protection.

Barriers Evidence on to PHC and UHC

Financing: Nigeria's health budget is 4.2% of national budget vs 15% Abuja Declaration (FMOH, 2023). This violates Wagstaff's ability-to-pay principle. Governance: Weak LGA accountability. Ward Health Committees exist in only 28% of wards (FMOH, 2023). Workforce: Brain drain of 10,000 doctors 2016-2023. WHO recommends 1 doctor per 600 people. Nigeria has 1 per 4,700 (WHO,2025). Inequity: Service coverage index is 45/100. North-East coverage is 29% vs South-West 61% (World Bank, 2025).

Gap in Literature

Most studies treat PHC and financing separately. Few apply both WHO PHC Framework and Wagstaff's Financing Equity Framework together to analyze Nigeria's post-2023 context of subsidy removal and NHIA Act. This study fills that gap by showing that PHC strengthening without financing reform, and financing reform without PHC strengthening, will both fail to achieve UHC.

Methodology

The study adopted desk review and secondary data analysis. Data were collected from WHO Global Health Observatory, World Bank WDI 2025, FMOH Nigeria Health Facility Survey 2023, BHCPF reports, peer-reviewed journals 2015-2026. Data were analyzed through thematic analysis using the WHO PHC Framework and Wagstaff's Framework to assess service delivery and financing gaps.

Discussion of Findings

Service Delivery Gap - WHO Framework: PHCs lack integration. Only 30% provide 24hr services. Community engagement is weak. Multi sectoral action on water and nutrition is limited. This explains poor coverage. Financing Equity Gap - Wagstaff Framework: 70% out-of-pocket violates equity. Risk pooling is low with only 4% insurance coverage. BHCPF is underfunded at $0.50 per capita vs recommended $86. The poor pay most. Global Lessons: Thailand and Rwanda succeeded because they harmonized PHC delivery and equitable financing. Ethiopia shows community health workers can extend coverage. Pathway for Nigeria: Apply both theories: Strengthen PHC service delivery per WHO and reform financing per Wagstaff through insurance expansion, increased budget, and strategic purchasing.

Conclusion

This paper demonstrates that UHC in Nigeria will not be achieved by addressing service delivery or financing alone. Using the WHO PHC Framework and Wagstaff's Health Financing Equity Framework, we see that both pillars must be strengthened simultaneously. Nigeria's PHC system is under-resourced and fragmented, while financing relies heavily on out-of-pocket payments. This creates a double burden: people cannot access services, and when they do, they face financial hardship. Global evidence from Thailand, Rwanda, and Ethiopia shows that harmonizing PHC strengthening with equitable financing works. For Nigeria to meet SDG 3.8, it must invest in PHC infrastructure, workforce, and community systems, while expanding health insurance and reducing out-of-pocket spending.

In conclusion, PHC is the vehicle and equitable financing is the fuel for UHC. Without both, the journey to equitable health systems will stall. Political commitment, increased domestic resources, and community engagement are non-negotiable.

Recommendations

1. Adopt WHO PHC approach: Integrate services, strengthen LGA governance, and empower communities through Ward Health Committees.
2. Apply Wagstaff's financing principles: Increase health budget to 15%, scale BHCPF to $86 per capita, expand state health insurance, reduce out-of-pocket to less than 20%.
3. Human resources: Recruit, train and retain community health workers with incentives to reduce brain drain.
4. Digital health: Use DHIS2 and telemedicine to improve PHC data and access.
5. Multi sectoral action: Address WASH, nutrition, and social determinants as part of PHC.

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INTERNATIONAL TRADE AND THE PERFORMANCE OF THE NIGERIAN ECONOMY

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ABSTRACT

This study investigates the effect of international trade on economic performance in Nigeria. The aim of this study was to empirically evaluate the impact of international trade on economic performance in Nigeria over the time frame of 1992 to 2023. The study utilized secondary date, which was sourced from statistical bulletin of Central Bank of Nigeria of various issues and CBN annual reports. In analysing the dynamic relationship between the economic performance Index and selected international trade proxies such as Aggregate Export, Aggregate Import, Official Exchange Rate and Trade Openness. The study utilized Ordinary Least Square to capture the short and long run relationship. The result revealed the existence of a positive and significant relationship between aggregate import and trade openness and economic performance Index in Nigeria, while it was also revealed that, there is no significant relationship between aggregate export and official exchange rate and economic performance Index in Nigeria. consequently, the study recommends amongst others that; Export promotion strategy should be review and import substitution strategy should also be review so that import and export will change its dimension; Government should ensure that only capital goods that are essential in promoting economic performance should be imported, since not all importation are necessary for economic growth.

Keywords: International Trade, Economic Performance, Aggregate Export, Aggregate Import

BLOCKCHAIN TECHNOLOGY AND THE FUTURE OF FINANCIAL REPORTING: OPPORTUNITIES AND CHALLENGES FOR NIGERIAN BUSINESSES

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ABSTRACT

The rapid development of blockchain technology is transforming traditional approaches to accounting, financial reporting and business transactions. Blockchain provides a decentralized and tamper-resistant digital ledger capable of recording transactions in a transparent, traceable and secure manner. This study examines the opportunities and challenges associated with blockchain technology for the future of financial reporting among Nigerian businesses. The paper adopts a conceptual approach based on a review of relevant literature on blockchain, accounting information systems, financial reporting and emerging digital technologies. The study argues that blockchain has the potential to improve the reliability, transparency, timeliness and verifiability of financial information by creating permanent and traceable transaction records. It may also reduce opportunities for fraudulent alterations of accounting records, improve audit trails and facilitate more efficient verification of financial transactions. However, the adoption of blockchain technology in Nigeria faces significant challenges, including inadequate technological infrastructure, high implementation costs, limited technical expertise, cybersecurity concerns, regulatory uncertainty and resistance to technological change. The paper further highlights the need for accountants and auditors to acquire relevant digital competencies to remain effective in an increasingly technology-driven accounting environment. It concludes that blockchain could significantly reshape financial reporting in Nigeria if supported by appropriate regulatory frameworks, investment in digital infrastructure, professional training and effective cybersecurity measures. The study recommends collaboration among regulators, professional accounting bodies, universities and businesses to develop policies and competencies that will facilitate responsible blockchain adoption.

Keywords: Blockchain Technology, Financial Reporting, Accounting, Transparency, Audit Trail, Nigeria.

BIG DATA ANALYTICS AND MODERN ACCOUNTING PRACTICES: IMPLICATIONS FOR THE ACCOUNTING PROFESSION IN NIGERIA

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ABSTRACT

The emergence of big data analytics has created significant opportunities for transforming accounting practices and enhancing the quality of financial and managerial decision-making. Modern organizations generate large volumes of structured and unstructured data from accounting systems, digital transactions, social media, customer interactions and other electronic platforms. This study examines the implications of big data analytics for modern accounting practices and the accounting profession in Nigeria. The study adopts a conceptual research approach based on an examination of existing literature on big data analytics, accounting information systems, auditing and contemporary accounting practices. The paper identifies several potential benefits of big data analytics, including improved financial forecasting, enhanced fraud detection, more effective risk management, real-time analysis of financial information and improved decision-making. The technology can also enable accountants to move beyond traditional record-keeping functions towards strategic advisory and analytical roles. Despite these opportunities, the adoption of big data analytics presents challenges, including inadequate digital infrastructure, data privacy concerns, cybersecurity risks, high investment costs, shortage of specialized analytical skills and resistance to technological change. The study argues that the future relevance of accounting professionals will increasingly depend on their ability to combine conventional accounting knowledge with data analytics, information technology and critical-thinking skills. The paper concludes that Nigerian businesses and accounting institutions should invest in appropriate technologies, professional training and updated accounting education to maximize the benefits of big data analytics. It recommends stronger collaboration between universities, professional accounting bodies, regulators and industry to prepare accountants for the evolving digital accounting environment.

Keywords: Big Data Analytics, Accounting Practices, Accounting Profession, Digital Transformation, Financial Information, Nigeria.

FROM INFORMATION FRAGMENTS TO KNOWLEDGE COHERENCE: RETHINKING NURSING STUDENTS' LEARNING IN THE ERA OF GENERATIVE AI

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ABSTRACT

Generative AI has transformed nursing students' access to information, but access does not ensure coherent knowledge clinically. Disconnected information may produce fragmented knowledge—not integrated into a meaningful whole (1). This issue is particularly important in nursing education, as effective learning requires the integration of theoretical concepts with clinical application (2).

AI functions as a powerful pedagogical scaffold for simulation and procedural skills practice; however, passive use may risk inducing cognitive offloading(3). Thus, the concern is whether students' question, connect, evaluate, and integrate information.

A more effective approach is to build learning around purposeful interaction between student reasoning and AI. Students should analyze a clinical problem and articulate their reasoning before using AI. AI outputs should then be treated as objects of inquiry rather than final answers. Comparing these outputs with students' reasoning and credible sources can strengthen critical thinking through evaluating evidence, challenging assumptions, identifying inconsistencies, and examining conceptual relationships. In this process, AI serves as a facilitator of exploration and information connection, while students retain responsibility for interpretation, integration, and judgment.

Therefore, educators should adopt a Hybrid-Scaffolded Model, using AI for iterative and stepwise practice while prioritizing human facilitation for deeper cognitive learning(3). This approach can be operationalized through case-based assignments requiring students to critique AI outputs, identify inaccuracies and unsupported claims, create concept maps to integrate clinical findings, and justify final decisions based on evidence. Assessment should therefore emphasize clinical reasoning, knowledge integration, and the application of knowledge to novel clinical situations rather than focusing solely on the correctness of the final answer. Supporting this approach, a three-arm parallel randomized controlled trial was conducted among first-year nursing students. Participants were randomly assigned to three groups: the AI-Enhanced Group, the Blended Teaching Group, and the Traditional Teaching Group. All three groups received instruction over a 16-week course following the same instructional structure but using different teaching tools and tutoring strategies. The AI-Enhanced Group used a generative AI-powered digital tutor integrated with a knowledge graph-based learning environment; the Blended Teaching Group used knowledge graph

learning resources with instructor support and feedback; and the Traditional Teaching Group received conventional instruction using lectures, textbooks, and slides. The results showed that, compared with the other two groups, the AI-Enhanced Group demonstrated better academic performance, knowledge graph comprehension, knowledge retention, and case-based inference accuracy(4). This finding suggests that, because AI provides easier and more continuous access than instructors, it may provide students with greater opportunities to receive, examine, and organize information and thereby practice and strengthen skills related to clinical judgment. Therefore, AI should preferably be used alongside other educational approaches as a learning assistant. In this context, the use of a knowledge graph can guide students toward purposeful use of AI and the organization of information and concepts through structured relationships, thereby supporting the development of critical thinking and logical reasoning.

Keywords: Nursing Students; Artificial Intelligence; Learning; Critical Thinking.

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WHO IS THE MONSTER? POSTHUMAN OTHERNESS AND THE CRISIS OF HUMAN EXCEPTIONALISM IN *I AM LEGEND*

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ABSTRACT

Francis Lawrence's *I Am Legend* (2007), starring Will Smith as Robert Neville, presents a post-apocalyptic world in which a viral outbreak has transformed most of humanity into infected beings. At first, the film appears to establish a clear distinction between the human and the monstrous, with Neville representing the last remnants of human civilisation and the infected positioned as its threat. However, this distinction becomes increasingly uncertain as the film unfolds. This paper examines how *I Am Legend* challenges the idea of human superiority by questioning who has the authority to define the human and the monstrous. The first objective of the paper is to examine how the film constructs and gradually unsettles the boundary between human and nonhuman identities. The second objective is to explore how Neville's position as the last surviving human exposes the limits of human exceptionalism and forces a reconsideration of the infected as an emerging form of life rather than simply as monsters. The theoretical framework draws primarily on Rosi Braidotti's posthumanist theory and Cary Wolfe's critique of human exceptionalism. Braidotti's understanding of the posthuman subject helps examine the instability of fixed human identities, while Wolfe's work provides a basis for questioning the hierarchy through which human life is privileged over other forms of existence. The paper argues that the film's central tension lies not simply in humanity's struggle for survival but in the collapse of the categories through which humanity defines itself. By shifting the position of the human from dominant species to endangered minority, *I Am Legend* invites a reconsideration of otherness, survival, and what it means to be human.

Keywords: Humanity, Human Exceptionalism, Otherness, Post-apocalyptic world, Posthumanism.

EFFECTS OF AGRICULTURAL EXTENSION SERVICE DELIVERY ON NUTRITIONAL STATUS OF STAPLE FOOD CROP FARMERS IN BENUE STATE, NIGERIA

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ABSTRACT

This study examined the effects of agricultural extension service delivery on nutritional status of staple food crop farmers in Benue State, Nigeria using 120 respondents for the study. Primary data were collected and analyzed using descriptive statistics, Body Mass Index (BMI) and Ordinary Least Square (OLS) regression. The socio-economic profile results shows that majority (91.7%) of the farmers were between 31 – 50 years of age, mostly male (68.3%) and married (78.3%). Majority (78.3%) have more than 10 years of farming experience, while 39.2% acquired secondary education and 66.7% had 1–10 members per household. Finding shows that only 46.7% of farmers had access to agricultural extension services with 92.9% of them received nutrition-related information. The nutritional status of farmers revealed that most (64.2%) of the farmers are overweight (BMI > 30.00). The regression analysis revealed R^2 value of 0.6402 with a highly significant F-statistic of 27.13, implying that about 64.0% of the variation in nutritional status were explained by the predictor variables. Key determinants include nutritional knowledge (0.5236, $p<0.01$), dietary diversity (5.8977, $p<0.01$), income (2.7286, $p<0.05$), access to inputs (0.1779, $p<0.05$), and access to extension services (0.2576, $p<0.01$), all of which has positive effects on nutritional status. Conversely, distance to health facilities (-0.7204, $p<0.01$) has a negative effect. In conclusion, agricultural extension service delivery and related factors significantly influence nutritional status. The study recommends that, a more integrated approach linking agriculture and health sectors is essential for improving the nutritional wellbeing of farming households.

Keywords: Agricultural Extension, Service Delivery, Nutritional Status, Staple Food Crops

INTRODUCTION

Agriculture still remains the main primary occupation of many rural households in Nigeria, providing employment and contributing to the national economy (Muhammed *et al.,* 2019). The development of the agricultural sector is intrinsically linked to sustained economic growth. A key driver for agricultural development is extension service delivery, which serve as a vital conduit for disseminating knowledge, technologies, and best practices to farmers (Rivera and Alex, 2020). Agricultural extension is the process of applying scientific research and knowledge to agricultural practices through farmers' education. It can be defined as a process where the beneficial products of research are taken to the farmers and problems of farmers are taken to research institution for solution (Musa and Ibrahim, 2021).

Agricultural extension services serve as vital conduits for disseminating knowledge, technologies, and best practices to farmers, with the overarching goal of enhancing agricultural productivity, sustainability, and rural livelihoods (Rivera and Alex, 2020). According to Food and Agriculture Organization (FAO) (2020), agricultural extension services encompass a wide range of activities, including training workshops, demonstration plots, farmer field schools and advisory support delivered by extension agents, NGOs, government agencies, and other stakeholders. Modern agricultural extension has expanded its focus beyond technology dissemination to include critical areas such as household nutrition.

According to Hawkes *et al*. (2019), nutritional status of individuals is a key determinant of human health and well-being as it influences physical and cognitive development, immune function and productivity. Poor nutritional status did not only affect individual health, but also undermines agricultural productivity and economic development, as malnourished farmers are more susceptible to illness and decreased work capacity (FAO, 2020). Farmers in developing countries are most often face with nutritional challenges

(monotonous diets that lack essential nutrients) despite their role as food producers (Jones *et al*., 2018). These challenges can lead to micronutrient deficiencies, malnutrition and food insecurity impacting the health and well-being of farming households (FAO, 2020). The dietary patterns of farmers are influenced by multiple factors such as cultural practices, food availability and income levels.

Addressing the nutritional challenges of farmers requires a multi-sectoral approach that integrates nutrition-sensitive interventions into agricultural programs and policies delivered through extension services (Anderson and Feder, 2019). Improving the nutritional status of farmers is essential not only for their health and well-being, but for achieving global food security and sustainable development goals. Thus, the role of agricultural extension in enhancing good nutritional status among farming households that boost agricultural productivity is widely acknowledged. Agricultural extension services directly impact the nutritional quality of staple food crops and that of farmers. Despite the recognized importance of agricultural extension services, there is limited empirical evidence on their specific effects on nutritional well-being of the farmers. It is against the backdrop of aforementioned that this study was conceived, hence the following research objectives to:

i. describe the socio-economic characteristics of the staple food crop farmers in the study area;

ii. examine the agriculture extension service delivery on nutrition to the staple food crop farmers;

iii. estimate the nutritional status of the staple food crop farmers in the study area, and

iv. determine the effects of the agricultural extension service delivery on the nutritional status of the farmers.

METHODOLOGY

This study was conducted in Benue State known as the "Food basket of the Nation," located in the Middle Belt Region of Nigeria. It lies between Latitude 6^0 25' and 8^0 8' North of the equator and Longitude 7^0 47' and 10^0 0' East of the Greenwich Meridian. The State of 4,219,244 (National Population Commission (NPC), 2006). However, the projected population as at 2025 was 7,130,234 given the growth rate of 2.8% (National Bureau of Statistics (NBS), 2025). The rainfall ranges between 1000mm to 1500mm, while the average temperature is about 32°C. The land mass area is 34,059 square kilometers with agriculture as the main occupation of the populace. Three-stages sampling technique was used to select respondents. The first stage involved random selection of one extension blocks from two Local Government Areas (Markudi and Otukpo). Second stage was random selection of three extension cells from each of the block selected, while the third stage was proportionate selection of 120 staple food crop farmers using Taro Yamane (1967) formula.

Primary data were collected using structured questionnaire complemented with an interview schedule. Data collected were analyzed using descriptive and inferential statistics as well as Body Mass Index (BMI). Descriptive statistics include frequency counts, percentages and mean. Body Mass Index (BMI) of the farmers was calculated as weight in kilograms divided by the square of height in meters (kg/m). This was categorized as Underweight (<20.0), Normal (20.01–30.00) and Overweight (>30.00) as adopted and modified from World Health Organization (WHO) (2020). Inferential statistics used was Ordinary Least Square (OLS) regression analysis. Ordinary Least Square (OLS) regression model in its implicit form is specified as;

$$Y = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_{8.....}X_{10}) \quad (1)$$

The explicit form of the model is specified as:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \ldots\ldots\ldots\ldots\ldots\ldots + \beta_{10}X_{10} + u \quad (2)$$

Where;

Y= Nutritional status of the farmers (measured using the body mass index (BMI) kilogram per meter)

X_1 = Nutrition education (years)

X_2 = Nutritional knowledge (perception scores)

X_3 = Distance to the nearest health facilities (kilometers)

X_4 = Dietary diversity (count of food groups consumed)

X_5 = Crop diversity (count of different crops grown)

X_6 = Household Income (Naira)

X_7 = marital status (dummy variable: 1 if married, 0 if otherwise)

X_8 = Access to inputs (dummy variable: 1 if yes, 0 if otherwise)

X_9 = Extension services (number)

X_{10} = Access to credit (Naira)

u = Error term

β_0 = Intercept

$\beta_1 - \beta_{10}$ = Coefficients of the variables

$X_1 - X_{10}$ = Predictor (independent) variables

RESULTS AND DISCUSSION

Socio-Economic Characteristics of the Farmers

The socio-economic characteristics results presented in Table 1 revealed majority (91.7%) of the farmers fall within the 31–50 years age bracket, representing economically active years. This indicates that staple food crops farming is dominated by mature and experienced individuals rather than youths. The dominance of middle-aged farmers implies a relatively stable workforce with adequate physical strength and decision-making capacity, although it may also suggest limited youth involvement in agriculture. In terms of gender distribution, most (68.3%) are male, compared to 31.7% who are female. This imbalance highlights the continued prominence of men in farming activities as women play a supportive or complementary role in agricultural production. The majority (78.3%) of the farmers are married, while 20.0% are single and 1.7% widowed. The high proportion of married individuals suggests a likelihood of stable household structures, which may contribute to the availability of family labour for farming activities and enhance productivity.

Table 1: Distribution of farmers based on their socio-economic characteristics (n = 120)

Variable	Category	Frequency	Percentage
Age (years)	20-30	10	8.3
	31-40	62	51.7
	41-50	48	40.0
Gender	Female	38	31.7
	Male	82	68.3
Marital Status	Married	94	78.3
	Single	24	20.0
	Widow(er)	2	1.7
Farming Experience (years)	1-10	24	20.0
	11-20	48	40.0
	21-30	46	38.3
	Above 30	2	1.7
Educational Level	Non-Formal	19	15.8
	Primary	20	16.7
	Secondary	47	39. 2
	Tertiary	11	9. 2
	Adult	23	19.1
Household Size	1-10	80	66.7
	11-20	40	33.3

Source: Field Survey, 2024

Farming experience among the farmers is relatively high with majority (78.3%) having between 11 – 30 years, indicating a knowledgeable and skilled farming population that can influence efficiency and responsiveness to agricultural innovations. Meanwhile, educational attainment among the farmers varies, with 39.2% attained secondary education, implying that literacy levels are fairly moderate. The predominance of secondary education suggests a reasonable capacity to understand and adopt improved farming techniques. Most (66.7%) of the farmers have household sizes ranging from 1–10 members, indicating a relatively high household sizes that can provide sufficient family labour for farming operations. These findings are in line with the study of Aliyu and Sani (2023) who reported that maize farmers in their study area are predominantly middle-aged, married, and experienced with moderate levels of education as well as relatively high household sizes. It suggests a farming population with considerable experience and labour capacity.

Agriculture Extension Service Delivery on Nutrition to the Farmers

The agricultural extension service delivery on nutrition to the farmers as presented in Table 2 revealed that 46.7% reported having access to agricultural extension services, while more than half (53.3%) did not have access to extension support, suggesting a significant gap in service coverage including nutrition-sensitive agricultural practices. Among those that had access to extension services, majority (92.9%) reported receiving information specifically on nutrition from extension agents. This suggests that there is a strong emphasis on integrating nutrition-related messages into advisory services. It reflects a positive orientation of extension programs toward nutrition-sensitive agriculture, even though overall access is poor.

In terms of specific nutrition-related extension delivery services received, the results show varying levels of emphasis encompassing crop selection and diversity (34.4%) indicating that roughly one-third of the farmers are being guided on diversifying crops, which is a critical pathway to improving both farm resilience and household nutrition. This is followed by food processing and preservation (30.0%) implying a moderate level of attention post-harvest losses management and enhancing food availability. More so, 24.4% of the farmers indicated that they received nutrition education, highlighting exposure to knowledge on balanced diets and proper feeding practices, 18.9% receiving information on health and hygiene practices, and 16.7% had access to guidance on dietary diversity information.

Table 2: Distribution of farmers based on agriculture extension service delivery on nutrition

Variables	Frequency	Percentage
Access to extension services		
Access	56	46.7
No Access	64	53.3
Information on nutrition		
Access	52	92.9
No Access	4	7.1
Nutrition-related information*		
Crop selection and diversity	31	34.4
Food processing and preservation	27	30.0
Nutrition education	22	24.4
Health and hygiene practices	17	18.9
Dietary diversity	15	16.7
Post-harvest handling	14	15.6

Source: Field Survey, 2024

Note: * implies multiple responses recorded

The least proportion (15.6%) of the farmers received information on post-harvest handling. These suggest that essential aspects of nutrition, particularly those linked to food utilization, safety and quality are not being sufficiently emphasized within extension service delivery. This finding agrees with the study of Omotayo and Eze (2020) who reported that farmers who participated in extension programs had improved knowledge of nutrition and food safety practices. Although, more attention is been given

to production-oriented aspects of nutrition domain such as crop diversity and food processing, while consumption-related and health-oriented aspects like dietary diversity, hygiene and post-harvest handling receive comparatively less emphasis.

Nutritional Status of the Farmers

The result of the farmer's nutritional status presented in Table 3 is classified using the Body Mass Index (BMI) as it provides important insight into the overall health and nutritional wellbeing of the farmers. The result shows that only a small proportion (6.7%) of the farmers fall within the underweight category, with BMI of less than 20.0. This indicates that a relatively small segment of the farmers is experiencing potential undernutrition, which may be associated with inadequate food intake, illness or poor dietary quality. Although this proportion is low, it still reflects the presence of some level of nutritional deficiency within the study area. This finding is in contrast with the study of Adeyemi *et al*. (2019) who reported that a significant proportion of the farmers in their study area were malnourished, despite their involvement in food production.

More so, 29.1% of the farmers fall under normal nutritional status category as defined by a BMI range of 20.01 to 30.00. This indicates that less than one-third of the respondents have a healthy body weight within the acceptable BMI range. Individuals in this category are generally considered to have an adequate balance between energy intake and expenditure, suggesting relatively good nutritional wellbeing. However, the fact that this group is not the majority points to an imbalance in the overall nutritional profile of the population. This finding agrees with that of Eze and Olayinka (2023) who reported a strong correlation between farming practices and the nutritional well-being of the farmers

The most dominant category is that of overweight individuals, accounting for 64.2% of the farmers having a BMI of greater than 30.00. This high proportion indicates a significant prevalence of overnutrition within the study population. This level of overweight status may be associated with excessive calorie intake, low physical activity, or dietary patterns high in fats and carbohydrates. Thus, the farmers are experiencing a nutritional transition, where issues of overnutrition are becoming more prominent than undernutrition. This is in line with the study of Omotayo and Eze (2020) who reported that farmers in their study area relied heavily on their crop for sustenance, leading to a monotonous diet lacking in essential nutrients. This could lead to excess body weight which may expose the farmers to diseases such as hypertension, diabetes and cardiovascular conditions.

Table 3: Distribution of the farmers based on their nutritional status

Nutritional status	Body Mass Index (BMI)	Frequency	Percentage
Underweight	(<20.0)	8	6.7
Normal	(20.01 - 30.00)	35	29.1
Overweight	(>30.00)	77	64.2
Total		120	100.0

Source: Field Survey, 2024

Effects of Agricultural Extension Service Delivery on the Nutritional Status of Farmers

The regression estimates on the effects of agricultural extension service delivery on the nutritional status of farmers is presented in Table 4. It revealed R-squared value of 0.6402 which implies that about 64.0% of the variation in nutritional status of the farmers are explained by the explanatory variables included in the model, while the remaining 36.0% is attributed to factors not captured. The overall significance of the model is confirmed by the F-statistic value of 27.13, which is significant at 1% level of probability. The nutritional knowledge (0.523594, $p < 0.01$) is highly significant and has a strong positive effect. This implies that an increase in nutritional knowledge significantly improves the nutritional status of respondents, highlighting the importance of awareness and understanding of proper dietary practices.

Similarly, dietary diversity (5.897665, $p < 0.01$) is significant and had a positive effect. This suggests that households with more diversified diets tend to have better nutritional outcomes, reinforcing the importance of consuming a variety of food groups. Income (2.728638, $p < 0.05$) is significant and has a positive effect on nutritional status. This implies that higher income improves nutritional outcomes,

likely through improved access to quality food, healthcare, and other welfare-enhancing services. Access to inputs (0.17791, $p < 0.05$) is significant and has a positive effect on nutritional status of farmers. This indicates that improved access to agricultural inputs contributes positively to nutritional status, likely through increased productivity and food availability.

Furthermore, access to extension services (0.2575, $p < 0.01$) is significant and has a positive effect on nutritional status of the farmers. This confirms that agricultural extension plays a critical role in improving nutritional outcomes by facilitating the dissemination of improved farming and nutrition-related practices. This finding corroborates that of Adeyemi *et al.* (2019) who reported that agricultural extension services improve the nutritional status of maize farmers in their study area. Farmers who had regular contact with extension agents were more likely to adopt improved farming practices leading to better nutritional outcomes. Meanwhile, distance to the nearest health facility (-0.7204, $p < 0.05$) is significant but has a negative effect on nutritional status. This indicates that as distance to health facilities increases, nutritional status worsens, likely due to reduced access to health services, nutrition counselling, and medical support.

Table 4: Regression estimates on effects of agricultural extension service delivery on farmers' nutritional status

Variable	Coefficient	Standard Error	t - value
Nutrition education	0.36819	0.225057	1.64
Nutritional knowledge	0.523594	0.089329	5.86***
Distance to health facilities	-0.72045	0.316125	-2.28**
Dietary Diversity	5.897665	2.162738	2.73***
Crop Diversity	-0.1814	0.211711	-0.86
Income	2.728638	1.230398	2.22***
Marital Status	-0.41843	1.77901	-0.24
Access to Inputs	0.177915	0.072163	2.47**
Extension Services	0.25758	0.090641	2.84***
Access to Credit	-1.2E-05	2.16E-05	-0.54
F-statistics	27.13***		
R – squared	0.6402		

Source: Field Survey, 2024

CONCLUSION

The study concludes that a majority of staple crop farmers are middle-aged (within their most productive age), male, married, and experienced individuals. Access to agricultural extension services remains limited, as less than half of the farmers reported receiving extension services on nutrition. Among those who had access, nutrition-related information was fairly well emphasized, particularly on topics such as crop selection, nutrition education, and food processing. The nutritional assessment reveals a critical public health challenge, with a high prevalence of overweight farmers with only a small proportion classified as normal or underweight, likely linked to a high-carbohydrate, low-diversity diet. Nutritional knowledge, dietary diversity, income, access to inputs and extension contacts are key positive determinants of nutritional status of the farmers. This confirms that agricultural extension service delivery plays a significant role in shaping nutritional outcomes.

RECOMMENDATIONS

Based on the findings of the study, the following policy recommendations are made:

The study recommended that the state government should strengthen the collaboration between agricultural extension services and health agencies to expand nutrition education among farmers. Also, community-based nutrition education programs should be implemented to promote balanced diets, dietary diversification, food utilization, hygiene and post-harvest handling to address both undernutrition and overnutrition challenges. In general, government and relevant stakeholders should expand the coverage of agricultural extension services by employing more trained extension personnel, improve mobility, and strengthen funding for extension activities to ensure wider reach, especially in

rural communities. More so, establishment of primary health centres or mobile health and nutrition services in rural areas will help improve access to healthcare and nutrition counselling, thereby improving overall nutritional status.

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EXPERIMENTAL INVESTIGATION OF VIBRATION DAMPING IN ALFA FIBER-REINFORCED CYLINDRICAL SHALLOW SHELLS

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Abstract:

Natural-fiber composites offer promising vibration damping properties for lightweight structural applications. This study focuses on the experimental damping behavior of cylindrical shallow shells reinforced with randomly distributed short Alfa fibers. Shell specimens with different fiber mass fractions and curvature levels were investigated using impact-hammer modal testing. The damping coefficients were determined from the vibration response for the first natural modes. The results highlight the important contribution of Alfa fibers to energy dissipation within the composite, mainly through fiber–matrix interfacial friction and the intrinsic damping characteristics of the constituents. The damping response is also influenced by vibration frequency, fiber content and shell curvature, with the highest damping levels observed for the fundamental mode. These findings demonstrate the potential of Alfa-fiber-reinforced composites for lightweight structures requiring improved vibration attenuation.

Keywords: Alfa fibers; Damping; Bio-composites; Cylindrical shallow shells; Vibration attenuation; Experimental modal analysis.

ARENE LIGAND ENGINEERING IN CHROMIUM HALF-SANDWICH COMPLEXES TOWARD ENHANCED DYE-SENSITIZED SOLAR CELL PERFORMANCE

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ABSTRACT

This work investigates the influence of arene-ligand functionalization on the photovoltaic properties of half-sandwich chromium complexes of the general formula (η^6-C_6H_5X)$Cr(CO)_3$. Seven functionalized derivatives were theoretically examined as potential sensitizers for dye-sensitized solar cells (DSSCs) using density functional theory (DFT) and time-dependent density functional theory (TD-DFT). Ground- and excited-state properties were calculated at the B3LYP/6-31G/SDD level. The photovoltaic performance of the complexes was assessed through key descriptors, including the maximum absorption wavelength (λmax), light-harvesting efficiency (LHE), electron-injection driving force (ΔG_{inj}), dye-regeneration driving force (ΔG_{reg}), and open-circuit voltage (V_{OC}). The calculated results demonstrate that structural modification of the arene ligand significantly affects the electronic, optical, and charge-transfer characteristics of the chromium complexes. Among the investigated compounds, DA, DB, DD, DF, and DG displayed the most favorable combination of photovoltaic parameters, indicating their potential as sensitizers for DSSC applications. Overall, these findings demonstrate the usefulness of DFT and TD-DFT approaches for predicting structure–property relationships and guiding the rational design of new organometallic sensitizers for solar-energy conversion.

Keywords: half sandwich chromium; DSSCs; optoelectronic; photovoltaic characteristics and DFT/ TD-DFT.

THE CASE AGAINST HYPOCRISY IN THE COMMUNITY: EXPLORATION OF JHONEL'S 1000 POEMS

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ABSTRACT

In traditional African settings, griots, bards, and other verbal artists played an important role in social regulation, social norm application and preservation, as well as in the transmission of moral values pertaining to their culture and civilization. Jhonel, a modern-day Nigérien slam artist of Zarma extraction, who performs in French and in Zarma, engages in an axiological evaluation of the Nigérien society in particular, and of sub-Saharan societies at large in the song that is analyzed in this article. In this slam poem, Jhonel states that he will tell the truth (his truth), to the members of the community, no matter the consequences that will befall him. Through this poem, Jhonel showed what he valued, the courses of action that are dear to him, and the practices that he considers reprehensible. Through our axiological scrutiny of his treatment of the Nigérien society, we the two co-authors show the values that are dear to us, the way we think he should have analyzed and understood his own society, and we point out our points of agreement and disagreement with him. Both Jhonel and us, are engaged in a axiological study: he, of the Nigérien society; we, of both the Nigérien society and Jhonel's assessment of that society.

Keywords: Nigérien slam poetry, African oral poetry, Jhonel, axiology, hypocrisy in the community.

MAGNETIC BEHAVIOR OF HIPERCO 50-TYPE SOFT MAGNETIC ALLOY: A MONTE CARLO SIMULATION

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ABSTRACT

Hiperco 50 is a high-performance Fe–Co–V soft magnetic alloy that combines high saturation magnetization, high Curie temperature, and good magnetic stability, making it attractive for advanced electromagnetic applications. In this work, Monte Carlo simulations based on the Ising model and Metropolis algorithm are employed to investigate the magnetic and thermodynamic behavior of Hiperco 50. The temperature dependence of magnetization, magnetic susceptibility, internal energy, and specific heat is analyzed to characterize magnetic ordering and the magnetic phase transition. In addition, hysteresis loops are simulated at different temperatures to evaluate the influence of thermal fluctuations on the magnetic response. The influence of the Fe–Co–V composition on magnetic ordering and thermal stability is investigated. The Curie temperature is determined from the temperature-dependent magnetic response, while the hysteresis behavior is used to assess changes in coercivity and magnetic reversibility with temperature. The obtained results provide a computational description of the magnetic behavior of Hiperco 50 and highlight the role of alloy composition and exchange interactions in determining its magnetic performance. This study demonstrates the potential of Monte Carlo simulations as an efficient tool for understanding and optimizing high-performance soft magnetic alloys for electromagnetic and energy-related technologies.

Keywords: Hiperco, Magnetic Alloy, Curie temperature, Monte Carlo Simulation

EFFECT OF HOME-BASED EXERCISE ON PHYSICAL PERFORMANCE AMONG POSTMENOPAUSAL WOMEN: A NARRATIVE REVIEW

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Background: Postmenopausal women experience a deterioration in physical performance associated with hormonal changes. Home-based exercise offers a low-cost, adherence-friendly alternative to supervised programs, though its comparative effect on physical performance measures is still not recognized.

Objective: To present a synthesis of knowledge `on the effect of home-based exercise interventions on physical performance among postmenopausal women.

Methods: Findings were synthesized narratively from studies evaluating home-based interventions (resistance, aerobic, balance, impact, and breathing-based) assessing outcomes including gait speed, Timed Up-and-Go (TUG), sit-to-stand, the Short Physical Performance Battery (SPPB).

Results: We found several studies from across countries, Home-based exercise interventions consistently improved at least one domain of physical performance, most reliably gait speed, functional mobility, and lower-limb strength/sit-to-stand performance, with grip strength improving less consistently. A Pakistani virtual-reality program improved TUG, functional reach, sit-to-stand, and grip strength. UK-based home resistance-and-balance sessions (30–35 minutes) improved strength and balance, while a Welsh home-based interval program achieved 85–96% adherence and reduced adiposity measures. Voluntary continuation of home exercise post-intervention was associated with better retention of gains. A Korean trial found supervised resistance training outperformed home-based training on grip strength and SPPB.A French study combined breathing exercises with strength assessments, suggesting value in integrating respiratory and neuromuscular training. An Australian home-based unilateral hopping program improved chair-stand and stair-climb times.

Conclusion: Home-based exercise is shown to improve gait speed, mobility, and lower-limb strength in postmenopausal women, though supervised programs may achieve superior gains, particularly for grip strength and composite performance measures, underscoring the need for further dedicated home-based research in this population.

Key words: Menopause, Sit-to-stand, Grip strength

DOPANT-INDUCED BANDGAP ENGINEERING AND CHARGE-CARRIER DYNAMICS IN Sb/In-Doped Se–Te AMORPHOUS THIN FILMS

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Amorphous chalcogenide thin films offer considerable potential for photodetectors and optoelectronic devices owing to their tunable optical bandgap and defect-mediated charge transport [1,2]. In the present work, the structural, optical, electrical, and photoelectrical properties of $Se_{80}Te_{20-(x+y)}Sb_xIn_y$ thin films (x = 0, 5; y = 0, 5) were systematically investigated to understand the influence of Sb and In incorporation on localized states and carrier transport. Bulk alloys were synthesized by the melt-quenching technique and subsequently deposited as ~250 nm thick films by vacuum thermal evaporation. X-ray diffraction and scanning electron microscopy confirmed the amorphous and homogeneous nature of the deposited films. Optical measurements revealed a pronounced composition-dependent variation in the optical bandgap, decreasing from 1.20 eV for $Se_{80}Te_{20}$ to 1.07 eV with Sb incorporation, followed by an increase to 1.33 eV upon subsequent In incorporation. These changes are attributed to the competing effects of structural disorder, defect-state density, and modification of local bonding environments [3]. Electrical measurements demonstrated thermally activated conduction through localized states, with Sb/In incorporation enhancing dark conductivity by approximately one order of magnitude. Steady-state photoconductivity exhibited a sub-linear dependence on light intensity, with power-law exponents close to 0.5, indicating dominant bimolecular recombination in the presence of a continuous distribution of trap states [4]. Transient photoconductivity further revealed non-exponential photocurrent decay and composition-dependent differential lifetimes, confirming trap-assisted carrier recombination. The results establish a clear correlation between dopant-induced structural modification, optical bandgap evolution, defect states, and photocarrier dynamics, demonstrating the potential of Sb/In engineering for tailoring Se–Te chalcogenide thin films for photoconductive and infrared optoelectronic applications.

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ENHANCING THERMAL PERFORMANCE IN INDUSTRIAL COOLING SYSTEMS VIA ELLIPTICAL TUBES AND ADVANCED BAFFLE DESIGNS

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A B S T R A C T

This study compares the performance of four heat exchangers, which will be divided into two stages to optimize outcomes. First, a comparison is made between a shell-and-tube heat exchanger with a 25% baffle cut and tubes with different cross sections: circular (STHE-CT), elliptical with a 90° attack angle (STHE-ET90°), and elliptical with a 0° attack angle (STHE-ET0°). This comparison is based on a numerical analysis at the same flow rate; therefore, ANSYS Fluent was used to perform a three-dimensional computational study. The results revealed that the STHE-ET90° has the highest overall heat transfer coefficient. The second comparison is between the STHE-ET90° and heat exchangers with triple-layer flower baffles and ellipsoidal tubes with an attack angle of 90° (STHE-FB-ET90°). Temperatures, pressure drop on the tube, and shell sides are also examined for each case study.

Keywords: Heat exchanger, Temperature drop, Pressure drop, CFD.

COMPARATIVE ASSESSMENT OF EXTENSION AND ADVISORY SERVICE NEEDS OF CEREAL CROP FARMERS IN NASARAWA AND PLATEAU STATES, NIGERIA

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ABSTRACT

This study comparatively assessed the extension and advisory service needs of cereal crops farmers in Nasarawa and Plateau States, Nigeria. Multi-stage sampling procedure was employed to select 339 respondents for the study comprising of 171 and 168 from Benue and Nasarawa States, respectively. Primary data were collected from the respondents with the aid of structured questionnaire complemented with an interview schedule and analysed using descriptive statistics (frequency count, percentages and mean). The results revealed that mean age of the farmers in Nasarawa and Plateau States was 43 and 46 years, mean household size was 5 people, and mean farming experience was 21 years, respectively. The result on the cereal crops grown by the farmers revealed that maize is the predominant in Nasarawa (82.80%) and Plateau (88.40%) States. The topmost extension service needs of the farmers in Nasarawa State were on improve planting materials (84.70%), improve seeds (84.00%) and improve fertilizer (79.10%), while those of Plateau State was also on improve planting materials (91.30%), improve seeds (84.90%) and improve fertilizer (75.60%). Similarly, the topmost advisory service needs of the farmers in Nasarawa State were on better farm management (83.40%), agri-business (81.60%), health management and farm record keeping (77.30%), while those of Plateau State was agri-business (76.70%), livelihood diversification (72.70%) and improve well-being (75.60%). In conclusion, the farmers expressed strong demand for extension and advisory services that could boost their cereal crops production. Thus, the study recommended that; policy makers should prioritize scaling-up farmer field schools, participatory technology trials, and demonstration plots to enhance production capacity of farmers.

Keywords: Assessment, Extension and Advisory Services, Farmers' Needs, Cereal Crops

INTRODUCTION

The term "extension" has changed over time. It is moving away from the dominant emphasis on technology transfer (Swanson *et al.,* 2010). According to Agwu *et al.* (2023), it is a system that facilitate farmers access to knowledge, information and technology which aid their interaction with partners in research. George and Jeffrey (2020) posited that extension have three important components which are educational, economic and social. Therefore, agricultural extension describes the services that provide rural people access to knowledge and information for increase and sustain productivity. Food and Agriculture Organization (FAO) (2021) posited that agricultural advisory services enable farmers to produce farm-level solutions by establishing service relationships with advisors. It is all about informing, teaching and advising farmers regarding improved technologies and practices as well as other needs based on feedback mechanism. Davies *et al.* (2025) defined extension and advisory services as 'consisting of all the different activities that provide information and services needed by farmers and other actors in rural setting. It aimed to assist the farmers in developing their own technical, organisational and management skills that will help to improve the livelihoods rural household.

Over the years, extension systems are becoming more participatory and farmer's driven with new knowledge and skills for dissemination (Davies *et al.*, 2025). Intensive extension and advisory services are key to achieve the desired change (Farnwortha and Colverson, 2015). Meanwhile, agricultural extension and advisory service delivery are faced with series of challenges to meet the ever-increasing needs of farmers (Agwu *et al.*, 2023). In Nigeria, key problem areas include technological issues, inadequate linkages, insufficient technical and extension training, mobility constraints, equipment

shortages, lack of teaching aids and organizational deficiencies which all constituted a gap to address. To overcome these challenges, the role of extension and advisory services has to be well defined. It is also equally important to access farmers' felt-need in relation to extension and advisory services. Thus, the research outcome is expected to extend the frontiers of knowledge and add to the pool of existing literature on the subject matter. It will be of great benefits to relevant stakeholders including policy-makers, agricultural project/programme planners, donor agencies, academia, students, teachers, researchers and the general public who may find the research useful for policy intervention and references. Based on the aforementioned, the study attempts to provide answer to the following research objectives which are to:

i. describe the socio-economic profiles of the cereal crop farmers;

ii. examine the various cereal crops grown, and

iii. assess the extension and advisory needs of the cereal crop farmers in the study area

METHODOLOGY

The study was carried out in Nasarawa and Plateau States, Nigeria. Nasarawa State lies between Latitude 7° 45′ and 9° 25′ North, and Longitude 7° 00′ and 9° 37′ East. It had a population of 1,863,275 (NPC, 2006) which was projected to be 3,245,874 as at 2023 using 3.0% growth rate (National Bureau of Statistics (NBS), 2024). Annual rainfall ranges from 1100mm to 2000mm, while the mean temperature ranges from 25˚C in the month of October to 36˚C in March. More so, Plateau State lies between Latitudes 8°24′ and 10°48′ North of the equator, and Longitudes 8° 32′ and 10° 38′ East of the Greenwich meridian. It had a population of 3,206,531 (NPC, 2006) which was projected to be 5,032,628 as at 2023 using 2.7% growth rate (NBS, 2024). The mean annual rainfall varies between 1317.5 mm in the Northern part to 1460 mm in the Southern part of the State with an average temperature of 22°C.

Three-stage sampling procedure was used to select respondents for the study. The first stage involved random selection of one LGA from each of the Agricultural Zones in the State. The second stage was Proportionate selection (10%) of the total villages from each of the LGAs selected to get 24 villages. The third stage involved proportionate selection of the respondents using Taro Yamane (1967) formula for sample size determination as used by Muhammed *et al.* (2023). Primary data were collected using structured questionnaire complemented with interview schedule. Well-trained enumerator assisted the researcher in the data collection. Descriptive statistics such as mean, frequency counts and percentages were used to analyzed the data collected.

RESULTS AND DISCUSSION

Socio-Economic Profile of the Cereal Crop Farmers

The result of age distribution as presented in Table 1 shows that farming activities in both states are dominated by individuals in their economically active years. In Nasarawa State, majority (98.1%) of the farmers fall within the age of 31–50 years with a mean age of 43 years, while 89.5% of the farmers in Plateau State, were between the age of 31–50 years with mean age of 46 years. This suggests that farming is still largely undertaken by individuals in their productive years, although older farmers were more in Plateau State. This age structure is advantageous for productivity, as they are typically more physically active and receptive to innovation. More so, in Nasarawa State, 73.6% of farmers are male compared to Plateau State where males constitute 64.0%. Gender distribution indicates that farming remains male-dominated in both states, though with notable female participation in Plateau State. Majority (90.2%) of the farmers in Nasarawa State and 81.4% in Plateau State were married indicating that farming is largely a family-based enterprise. The high proportion of married individuals suggests the availability of family labour, which could help reduce reliance on hired labour and lower production costs. In Nasarawa State, majority (92.6%) of the farmers had household size between 1–10 members with a mean household size of 5 members, while Plateau State exhibits a similar trend, with 88.4% of the farmers having household size within 1–10 members also with a mean household size of 5 members per household. This household size distribution shows that greater proportion of the farmers operate moderate household structures potentially limiting labour-intensive farming operations.

In terms of education, in Nasarawa State, majority (80.4%) of the farmers acquired formal education (primary, secondary and tertiary), while 88.4% of the farmers in Plateau State acquired formal education. Educational attainment reveals a relatively moderate literacy level among farmers, with notable differences between the two States. The mean years of formal schooling is 11 years for Nasarawa State and 12 years for Plateau State, indicating slightly higher educational attainment in Plateau State. This suggests that farmers in Plateau may be more capable of adopting improved agricultural technologies and responding to extension messages as compared to farmers in Nasarawa State. Farming experience shows that the farmers possess substantial practical knowledge of agriculture. In Nasarawa State, majority (78.6%) of farmers had 1–20 years of farming experience, while in Plateau State, 79.0% of the farmers had 1–20 years of farming experience. The mean farming experience of the farmers in both States is 21 years, respectively. This indicates presence of experienced farmers which suggests a strong base of indigenous knowledge. Overall, the socio-economic profile suggests that agriculture in both Nasarawa and Plateau States is characterized by active, moderately educated and experienced farmers operating within family-based systems, but constrained by gender disparities and limited youth participation. These findings are in corroboration with the study of Anthony *et al.* (2021) who reported that the respondents in their study were economically active and dominated by male gender highly experienced in farming activities.

Table 1: Socio-economic profiles of the cereal crop farmers

	Nasarawa (n = 163)		Plateau (n = 172)	
Variables	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Age (years)				
31–40	84	51.5	75	43.6
41–50	76	46.6	79	45.9
51–60	3	1.8	18	10.5
Mean	**43**		**46**	
Gender				
Male	120	73.6	110	64
Female	43	26.4	62	36
Marital status				
Single	9	5.5	28	16.3
Married	147	90.2	140	81.4
Divorced	5	3.1	3	1.7
Widower	2	1.2	1	0.6
Household size (number)				
None	10	6.1	19	11
1–5	85	52.1	107	62.2
6–10	66	40.5	45	26.2
11–15	2	1.2	1	0.6
Mean	**5**		**5**	
Educational status				
Non-formal	32	19.6	27	15.7
Primary	35	21.5	20	11.6
Secondary	61	37.4	64	37.2
Tertiary	32	19.7	58	33.7
Adult	3	1.8	3	1.7
Mean	**11**		**12**	
Farming experience (years)				
1–10	57	35	74	43
11–20	71	43.6	62	36
21–30	35	21.5	24	14
>30			12	7
Mean	**21**		**21**	

Source: Field Survey, 2024

Cereal Crops Grown by the Farmer

The result of cereal crops grown by the farmers presented in Table 2 revealed maize crop to be the most widely cultivated cereal in both states as indicated by 82.8% of the farmers in Nasarawa State and 88.4% in Plateau State. This dominance underscores maize's central role as a staple food and a key income-generating crop. Its adaptability, relatively short maturity period, and strong market demand likely explain its prominence across both regions. However, the slightly higher participation rate in Plateau could be attributed to a more favourable climatic conditions or stronger market incentives. Rice is also an important crop grown in both States as indicated by 55.8% of the farmers in Nasarawa State as compared to 61.6% of the farmers in Plateau State. This indicates that more than half of the farming population in both states is involved in rice production, reflecting its growing importance as a staple food in Nigeria. Meanwhile, the most striking contrast between the two states was observed in millet production. Majority (95.3%) of the farmers in Plateau State grow millet in sharp contrast to only 26.4% in Nasarawa State. This implies that millet is a dominant staple food crop in Plateau State, likely due to its strong tolerance to drought and suitability to agro-climatic conditions. The near-universal adoption of millet in Plateau points to a high level of crop specialization, which can be both an advantage and a risk. While specialization can enhance productivity and expertise, it also exposes farmers to systemic risks such as climate shocks, pests or market price fluctuations affecting that specific crop. Sorghum production also shows a notable disparity between the two States. In Nasarawa, 44.2% of the farmers cultivates sorghum, while in Plateau State, 76.7% of the farmers are involved in sorghum production. This implies that farmers in Plateau State are more engaged in the production of drought-tolerant cereals (millet and sorghum), possibly due to environmental conditions or established value chains for these crops. Sorghum's importance in Plateau may also be linked to its use in food processing and local industries such as brewing. These findings align with the study of Adisa *et al.* (2019) who reported that maize, rice, millet and sorghum are the dominant cereal crops grown in Northern Nigeria.

Table 2: Distribution of the farmers based on cereal crop grown

	Nasarawa (n = 163)		Plateau (n = 172)	
Cereal crops	**Frequency***	**Percentage**	**Frequency***	**Percentage**
Maize	135	82.8	152	88.4
Rice	91	55.8	106	61.6
Millet	43	26.4	164	95.3
Sorghum	72	44.2	132	76.7

Source: Field Survey, 2024

Note: * implies multiple responses recorded

Extension and Advisory Service Needs of the Cereal Crop Farmers

The result of extension service needs among the farmers in Nasarawa and Plateau States presented in Table 3 revealed improved planting materials as the most critical needs as indicated by 84.7% of the farmers in Nasarawa State and 91.3% in Plateau State. This is closely followed by 84.0% of the farmers that indicated the needs for improved seeds in Nasarawa State and 84.9% in Plateau State. These figures clearly indicate that access to quality genetic materials remains a major extension service needs in both States. The slightly higher demand in Plateau suggests either greater awareness of improved technologies delivered through extension agents. The demand for fertilizers, both organic and inorganic are very high, underscoring soil fertility issues. In Nasarawa, 79.1% of the farmers require improved organic fertilizers, while 77.3% demand improved inorganic fertilizers. Similarly, in Plateau, 75.6% of the farmers expressed the need for organic fertilizers and 71.5% for inorganic fertilizers. This implies

that farmers in both States recognize the importance of soil nutrient management. The slightly higher demand for organic fertilizers shows a growing awareness of sustainable soil management practices. Agro-chemicals also constitute a significant area of need, with 71.2% of the farmers in Nasarawa State and 66.9% in Plateau State. This implies that the need for agrochemicals is significant to overcome pests, diseases and weeds problems.

The slightly higher demand in Nasarawa State indicates greater pest pressure where agro-chemical is seen as effective solution. However, the need for improved farm implements shows a more noticeable divergence between the two States. In Nasarawa State, 71.2% of the farmers expressed the need for better farm tools and machinery as compared to 58.1% of the farmers in Plateau State. This implies that farmers in Nasarawa State need for the equipment for mechanization purpose. More so, the relatively lower demand in Plateau State could indicate better access to farm implements. Lastly, in Nasarawa State, 65.6% of the farmers expressed this need for improved animal breeds as compared to 52.3% of the farmers while in Plateau State. This implies that although livestock improvement is important, crop-related interventions currently take precedence among farmers. The lower demand in Plateau State may indicate a stronger focus on crop production relative to livestock. These findings are in agreement with the study of Sani *et al.* (2020) who reported that farmers had a strong and consistent demand for improved agricultural inputs and technologies, particularly those directly linked to crop productivity such as seeds, planting materials and fertilizers.

Table 3: Extension service needs of the cereal crop farmers

	Nasarawa (n = 163)		Plateau (n = 172)	
Variables	**Frequency***	**Percentage**	**Frequency***	**Percentage**
Improved planting materials	138	84.7	157	91.3
Improved seeds	137	84.0	146	84.9
Improved organic fertilizer	129	79.1	130	75.6
Improved inorganic fertilizer	126	77.3	123	71.5
Improved agro-chemicals	116	71.2	115	66.9
Improved farm implements	116	71.2	100	58.1
Improved animal breeds	107	65.6	90	52.3

Source: Field Survey, 2024

Note: * implies multiple responses recorded

In the same vein, the result of advisory service needs among the farmers in Nasarawa and Plateau States presented in Table 4 revealed a broad and multifaceted demand for knowledge-driven support systems that extend well beyond conventional agricultural extension. Majority (83.4%) of the farmers in Nasarawa State expressed need for better farm management as compared to 68.6% of the farmers in Plateau State. This underscores the importance of strengthening farm management advisory services, especially in Nasarawa State, through practical, context-specific training that enhances planning, monitoring and resource utilization.

Closely aligned with this is the high demand for agribusiness advisory services as indicated by 81.6% of the farmers in Nasarawa State and 76.7% in Plateau State. This trend signals a shift away from subsistence farming toward commercialization where farmers are willing to engage more deeply with market-related agricultural activities but require the necessary knowledge and institutional support to do so effectively. The near parity figures across both states suggests a shared recognition among farmers

that agriculture is increasingly a business venture requiring skills in marketing, value addition, pricing, and enterprise development.

The need for improved financial management is also notably high as indicated by 77.3% of the farmers in Nasarawa State and 66.3% in Plateau State. This indicates that a significant proportion of farmers struggle with financial planning, budgeting and efficient use of credit. The higher demand in Nasarawa State again points to greater gaps in financial literacy. Health management emerges as another critical area as indicated by 77.3% of the farmers in Nasarawa State and 65.1% in Plateau State. This reflects the recognition that health directly influences labour productivity and farm performance. The importance of proper farm record keeping is also evident as indicated by 76.1% of the farmers in Nasarawa State and 66.3% in Plateau State. These results reveal that many farmers lack the capacity to maintain accurate records of inputs, outputs, and financial transactions, which are essential for evaluating farm performance and accessing formal credit. The gap is more pronounced in Nasarawa, reinforcing the need for targeted training and the introduction of simple, practical record-keeping tools that farmers can easily adopt.

Advisory needs related to improved livelihood and well-being are similarly high as indicated by 76.1% of the farmers in Nasarawa State and 69.2% in Plateau State. This suggests that farmers are concerned not only with agricultural output but also with broader issues affecting their quality of life, including income stability, food security and social welfare. Leadership development is another area of advisory need as reported by 70.6% of the farmers in Nasarawa and 61.0% in Plateau State. This indicates that farmers recognize the value of leadership skills in enhancing collective action, improve access to resources and strengthen bargaining power in markets.

Table 4: Advisory service needs of the cereal crop farmers

	Nasarawa (n = 163)		Plateau (n = 172)	
Variable	**Frequency***	**Percentage**	**Frequency***	**Percentage**
Better farm management	136	83.4	118	68.6
Agri-business	133	81.6	132	76.7
Improved financial management	126	77.3	114	66.3
Health management	126	77.3	112	65.1
Appropriate farm record keeping	124	76.1	114	66.3
Improved livelihood / well-being	124	76.1	119	69.2
Leadership development	115	70.6	105	61.0
Livelihood diversification	111	68.1	125	72.7
Training	108	66.3	106	61.6
Market and weather information	101	62.0	88	51.2
Workshops / Seminars	114	69.9	95	55.2
Skills acquisition & vocation	103	63.2	106	61.6
Social networking	96	58.9	103	59.9

Source: Field Survey, 2024

Note: * implies multiple responses recorded

However, the need for livelihood diversification presents a slightly different pattern, with farmers in Plateau State showing a higher demand (72.7%) as compared to Nasarawa State (68.1%). This suggests that Plateau State farmers may be more focused on spreading risk and enhancing resilience through multiple income sources. Training, workshops and seminars also reflect vital area of demand. Most (66.3%) of the farmers in Nasarawa State and 61.6% in Plateau State indicated the need for training, while workshops and seminars are needed by 69.9% of the farmers in Nasarawa State as compared to 55.2% in Plateau State. This disparity suggests that farmers in Nasarawa State have fewer opportunities for formal capacity-building engagements.

Access to market and weather information is equally an important area of advisory needs as reported by 62.0% of the farmers in Nasarawa State and 51.2% in Plateau State. This highlights a gap in timely and reliable information, which is crucial for decision-making in an increasingly climate-sensitive and market-driven agricultural environment. Lastly, there is also advisory need for skills acquisition and vocational training as reported by 63.2% of the farmers in Nasarawa and 61.6% in Plateau State, while need for social networking was indicated by 58.9% of the farmers in Nasarawa and 59.9% in Plateau State. These areas reflect broader capacity development and knowledge exchange, which can foster innovation and collaboration among farmers. These findings corroborate that of Davies *et al.* (2021) who reported that farmers require a comprehensive advisory service system that integrates technical, economic, social and institutional dimensions. Extension systems need to evolve from traditional technology transfer models into holistic advisory frameworks that address farm management, agribusiness development, financial literacy, health, and social empowerment.

CONCLUSION

Based on the findings of this study; It was concluded that majority of farmers in the study area were in their productive age and were predominantly male, married with an average household size of five persons. They acquired formal education and highly experienced in cereal crops production. Both States share a common interest in maize and rice production, but Plateau State demonstrates a much higher level of diversification into drought-tolerant cereals like millet and sorghum. The topmost extension service need of the farmers was improved planting materials, seeds, organic and inorganic fertilizers, while topmost advisory service need was better farm management, agribusiness, improved financial and health management.

RECOMMENDATIONS

In line with the major findings of the study, the following recommendations were put forward:

i. It is recommended that policy makers should promote inclusive extension and advisory services that promote cereal production. More so, there is need for investments in improved seed systems, extension services, climate-smart agriculture practices and market access critical for enhancing productivity, resilience, and farmer livelihoods.

ii. Policy makers should prioritize scaling up farmer field schools, participatory technology trials, and demonstration plots to enhance adoption. Extension agencies should integrate agribusiness and financial literacy training to help farmers transition from subsistence to market-oriented production. Such findings emphasize the need for extension services to integrate livelihood improvement strategies, including income diversification, nutrition, and social protection measures.

iii. Government and international agencies should partner to increase budgetary allocation for funding extension and advisory services in the country and the study area in particular.

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PRODUCTION OF COMPOSITE BRIQUETTES FROM CHARRED AND UNCHARRED COCONUT SHELL FILLED WASTE PAPER AND STARCH BINDER

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ABSTRACT

Nigeria's growing dependence on firewood and charcoal for domestic energy has placed increasing pressure on forest resources, while large volumes of coconut shell and waste paper are routinely discarded without productive use. This study set out to produced briquettes from charred and uncharred coconut shell. The shells were combined in five ratios, from 45:35 to 60:20, using a fixed binder made up of 10% waste paper pulp and 10% starch. The coconut shell was first grounded, then carbonised at 500°C for two hours before being blended, compacted at 10 kN, and oven-dried at 105°C. The resulting briquettes were tested for moisture content, density, ash content, durability, water absorption, ignition time, and burning time. Moisture content ranged from 18.21% to 19.64%, density averaged 0.693 g/cm³, and ash content stayed low at 2.10–2.41%, all pointing to reasonably clean-burning fuel. Ignition times of 27–35 seconds and burning times of 40–54 minutes were recorded, with the formulation containing 60% charred and 20% uncharred coconut shell (Sample E) performing best overall, igniting fastest and burning longest. Durability and water absorption, on the other hand, were less favourable, suggesting the paper–starch binder still needs refinement. Overall, the findings support the idea that coconut shell and waste paper can be converted into a viable, low-ash alternative to firewood, offering both an environmental and an energy benefit, even though further work on moisture control and mechanical strength is needed before the product could be considered commercially ready.

Key words: coconut, briquettes, ignition time, fuel, binder, composites

INTRODUCTION

The world's continuing reliance on fossil fuels, alongside the environmental costs that come with it, has pushed researchers to look more seriously at renewable alternatives. Biomass stands out among these options because it is abundant, renewable, and broadly carbon-neutral, and briquetting has become one of the more practical ways of converting loose agricultural residues into a denser, more usable solid fuel (Bot et al., 2022). By compressing biomass into briquettes, bulk density goes up and moisture content goes down, which in turn makes the material easier to store, transport, and burn efficiently (Kpalo et al., 2020). In many developing countries this matters beyond convenience: briquettes offer households a genuine substitute for firewood, easing the pressure that fuelwood collection places on forests (Obi et al., 2022).

Not all biomass performs equally well once densified. Lignin content, cellulose structure, ash content, and volatile matter all shape how a briquette behaves, and high-lignin materials such as coconut shell are particularly well suited to carbonisation because the resulting char carries a high fixed-carbon fraction and a correspondingly higher calorific value (Kamdem et al., 2025). Carbonisation itself drives off volatile components and concentrates energy within the material, and recent work has increasingly explored composite briquettes that blend charred and uncharred biomass together. Combining the two forms tends to improve ignition and combustion stability, while organic binders such as waste paper pulp add the mechanical strength that loose char particles otherwise lack (Obi et al., 2022). Even so, getting the biomass ratio and processing parameters right remains an open question, since it directly determines calorific value, ash content, moisture retention, and overall burn quality (Orisaleye et al., 2024).

In Nigeria specifically, population growth and rising energy demand have deepened the country's dependence on firewood and charcoal, contributing to deforestation, land degradation, and indoor air pollution from incomplete combustion (Kpalo et al., 2020). At the same time, coconut shells and waste paper accumulate in large quantities and are often disposed of with little thought to their potential value. Turning these residues into composite briquettes therefore addresses two problems at once: it offers a cleaner household fuel and it gives otherwise wasted material a productive second life. This study was carried out with that dual purpose in mind, focusing on the production and characterisation of composite briquettes made from charred and uncharred coconut shell, bound together with waste paper pulp and starch.

The specific aim was to produce composite briquettes from charred and uncharred coconut shell using starch and waste paper as binder, in order to achieve improved combustion efficiency and enhanced mechanical strength. To get there, the study worked through five objectives: carbonising coconut shell under controlled conditions; preparing composite briquettes at optimised ratios of charred shell, uncharred shell, starch, and waste paper; determining the proximate properties of the briquettes, including moisture and ash content; assessing physical and combustion behaviour such as density, ignition time, and burning time; and finally comparing the resulting briquettes against a conventional solid fuel, firewood.

RESEARCH AND FINDINGS

Materials and Methods

Coconut shells were sourced from a coconut seller at Samaru Market, Zaria, while waste paper (cardboard) and cassava starch were obtained from community business centres within Ahmadu Bello University. The coconut shells were sun-dried for several days to lower their moisture content, after which they were split into two batches: one carbonised to produce charred shell, and the other kept in its raw, uncharred form. Carbonisation was carried out in a carbonisation drum under restricted air supply, with the drum heated to 500°C for two hours inside a muffle furnace, allowing the char to cool under the same limited-oxygen conditions to prevent it from burning away completely, an approach consistent with standard slow-pyrolysis carbonisation procedures used for lignocellulosic biomass (Kamdem et al., 2025).

Waste paper was shredded, soaked in warm water for roughly 24 hours to soften the fibres, and then pulped by hand into a uniform slurry. A starch paste was separately prepared by dissolving 40 g of starch in 50 g of water and stirring this suspension into 495 g of boiling water until fully gelatinised, following the same gelatinised-starch binder approach reported by Sihotang et al. (2025). Both the charred and uncharred coconut shell were then crushed and sieved separately, the char through a 1 mm sieve and the uncharred material through a 2 mm sieve, to improve particle packing and binder contact, since finer, well-matched particle sizes are known to strengthen inter-particle bonding in composite briquettes (Yaseen et al., 2025).

Five formulations (Samples A–E) were prepared by varying the ratio of charred to uncharred coconut shell while keeping the binder fixed at 20% overall — 10% waste paper pulp and 10% starch — as summarised in Table 1. Each mixture was moistened, thoroughly blended, packed into a cylindrical mould, and compacted at 10 kN using a hydraulic briquetting press, a compaction range broadly consistent with pressures reported for good-quality biomass briquettes (Orisaleye et al., 2024). After compression, the briquettes were air-dried briefly before being oven-dried at 105°C for 24 hours to a constant weight. The finished briquettes were then characterised for moisture content, ash content, density, durability (tumbling test), water absorption capacity, ignition time, and burning time using standard laboratory procedures (Kpalo et al., 2020; Obi et al., 2022).



Plate 1. Composite briquette samples produced from the five formulations (A–E).

Table 1. Briquette formulations by proportion of charred and uncharred coconut shell

Sample	Charred coconut shell (%)	Uncharred coconut shell (%)	Starch (%)	Waste paper (%)
A	45	35	10	10
B	50	30	10	10
C	53	27	10	10
D	57	23	10	10
E	60	20	10	10

Results and Discussion

Moisture content across the five formulations ranged from 18.21% to 19.64%, with Sample A (45:35) retaining the most moisture and Sample E (60:20) the least, as shown in Figure 1. The general pattern, though not perfectly linear, was that raising the proportion of charred coconut shell lowered moisture content, which fits with the fact that carbonisation drives off much of the material's inherent moisture and volatile matter. That said, these values sit well above the 8.13% reported by Yirijor and Bere (2024) for coconut shell charcoal briquettes bound with cassava and corn starch, and above the 4.22% reported by Sihotang et al. (2025) for briquettes made from butt dust and coconut shell charcoal. The gap is most plausibly explained by the hygroscopic nature of the waste paper–starch binder used here, along with the inclusion of uncharred shell, which retains more moisture than fully carbonised material. The values obtained do, however, fall within the 5.8–19.88% range reported across blended biomass briquettes by Kamdem et al. (2025), suggesting they are not unusual for this class of composite fuel, even if further drying would clearly improve performance.

Figure 1. Moisture content of briquette samples

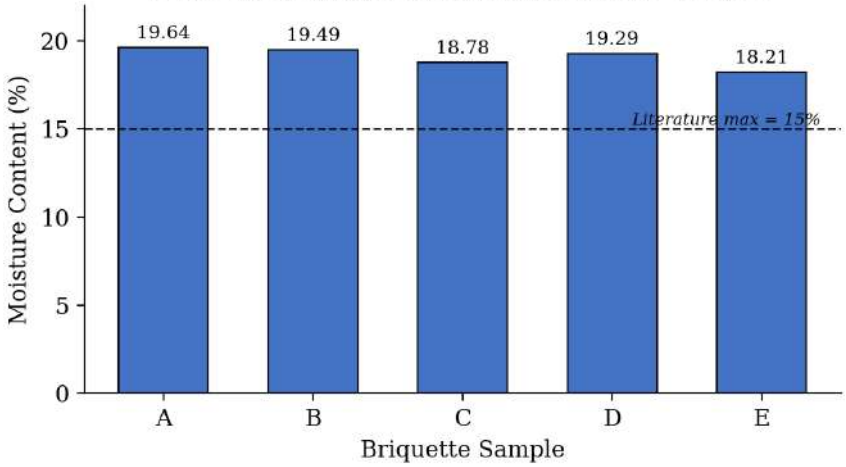

Figure 1. Moisture content of briquette samples A–E.

Density ranged narrowly from 0.683 to 0.698 g/cm³, averaging 0.693 g/cm³, with only minor variation across the formulations, as Figure 2 illustrates. This consistency is best explained by the fact that binder composition, particle size, mould dimensions, and compaction pressure (10 kN) were held constant throughout, leaving the charred-to-uncharred ratio with only a marginal influence on final density. The values obtained fall comfortably within the 0.60–1.00 g/cm³ range that Eling et al. (2024) describe as typical for well-densified biomass briquettes, and align with Orisaleye et al. (2024)'s observation that, once an adequate compaction pressure is reached, further changes to formulation produce only small density gains.

Figure 2. Bulk density of briquette samples

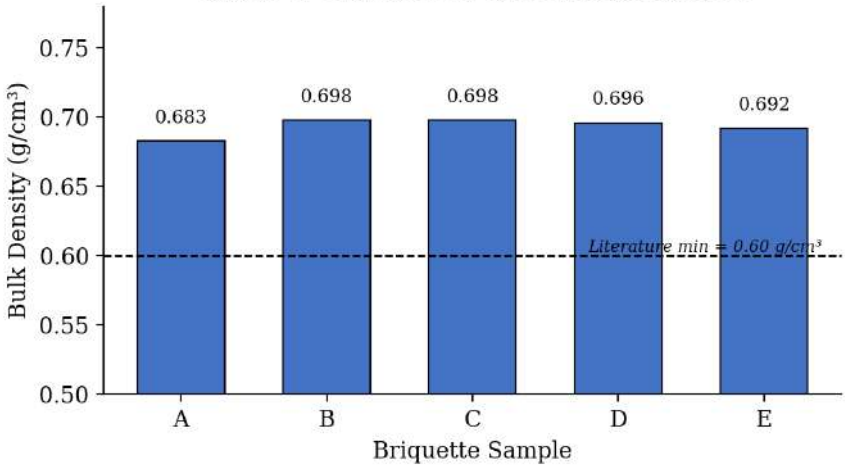

Figure 2. Bulk density of briquette samples A–E.

Ash content stayed low throughout, ranging from 2.10% to 2.41% (Figure 3), which is a genuinely encouraging result: low ash content generally signals cleaner combustion and less residue to manage after burning. Durability, measured by tumbling test, ranged from 42.17% to 43.21% (Figure 4), improving slightly as the proportion of charred coconut shell increased, most likely because carbonised particles interlock more tightly during compaction. Even so, the overall durability figures were modest and fell well short of the 90% benchmark often cited for high-quality briquettes, a pattern consistent with Orisaleye et al. (2024) and Yaseen et al. (2025), both of whom link weaker mechanical strength to higher moisture content and less-than-optimal particle size — exactly the conditions present in this study. Umeocho et al. (2024) similarly note that binder type and feedstock characteristics, not just binder quantity, govern briquette hardness, which helps explain why holding the binder ratio constant produced only marginal gains in durability across samples.

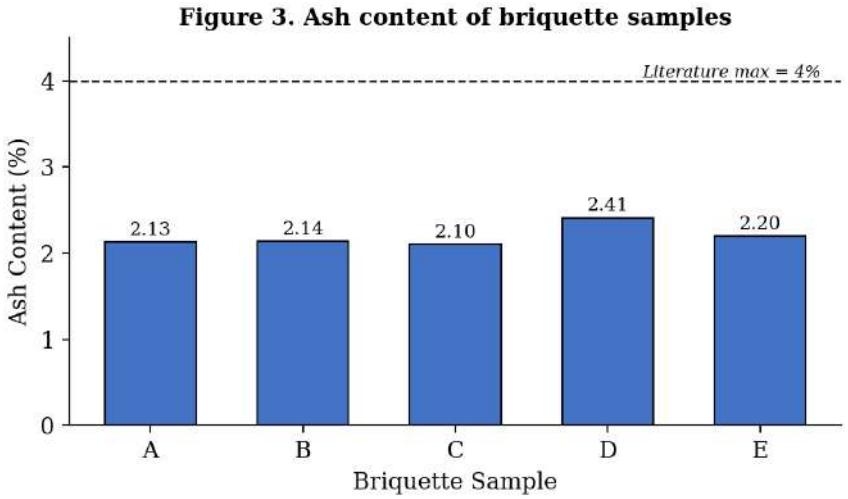

Figure 3. Ash content of briquette samples A–E.

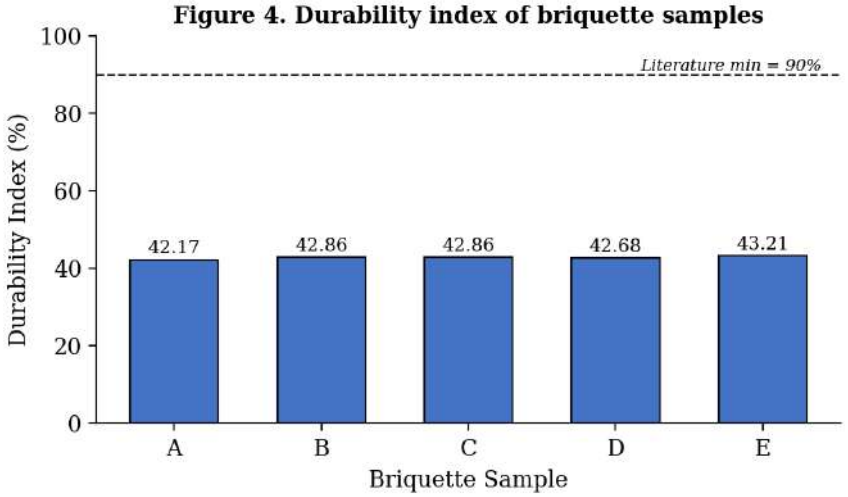

Figure 4. Durability index of briquette samples A–E.

Water absorption capacity was comparatively high, ranging from 66.27% to 78.75% (Figure 5), and generally rose with increasing charred content before tapering off slightly in Sample E. This trend tracks the porous structure that carbonisation creates, which gives water more pathways into the briquette matrix — an effect also reported by Turyamusiima et al. (2025) for carbonised coffee-husk composites. The hydrophilic nature of both waste paper and starch compounds this effect, since both readily attract moisture. Korol and Yankovych (2025) note that alternative binders such as polyvinyl alcohol markedly reduce water uptake, which points to binder reformulation as a promising direction for improving the moisture resistance of this briquette in future work.

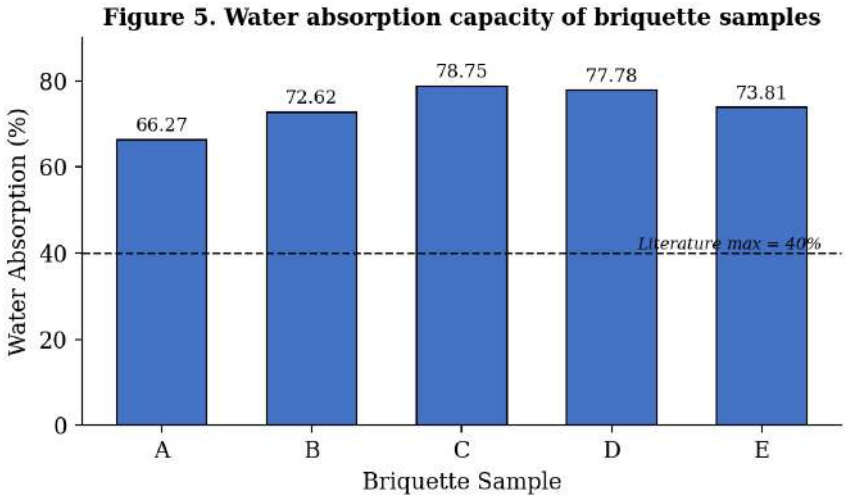

Figure 5. Water absorption capacity of briquette samples A–E.

Combustion performance told a more encouraging story. As Figure 6 shows, ignition time ranged from 27 to 35 seconds and burning time from 40 to 54 minutes, with Sample E — the formulation containing the highest proportion of charred coconut shell (60%) — consistently outperforming the others, igniting fastest and burning longest. The inverse relationship visible between the two bars for most samples is worth noting: formulations that ignited a little more slowly (such as Sample B) did not necessarily burn any longer, which suggests that ignition speed and burn duration are governed by somewhat different aspects of the char-to-raw-shell balance — surface porosity likely drives ignition, while overall carbon density drives burn duration.

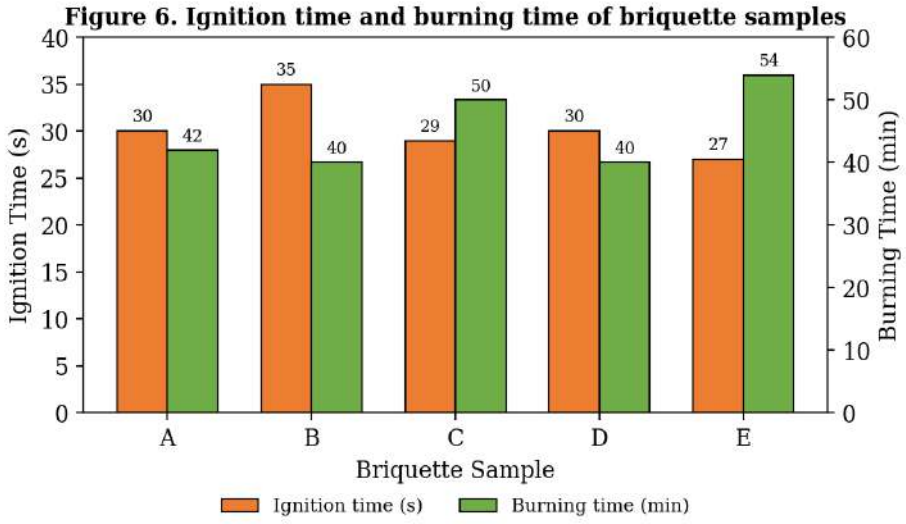

Figure 6. Ignition time and burning time of briquette samples A–E.

Taken together, these six figures point to a fairly consistent story: increasing the proportion of charred coconut shell improves ignition and burning performance and modestly improves durability, without meaningfully harming density or ash content, but it does little on its own to resolve the briquette's moisture, durability, and water-resistance limitations (Orisaleye et al., 2024; Yaseen et al., 2025). Sample E stands out as the best-balanced formulation, combining the lowest moisture content, the fastest ignition, and the longest burn time, even though its durability and water absorption remain areas for improvement. Compared with conventional firewood, the briquettes offer cleaner combustion and more predictable, uniform fuel characteristics, consistent with the household-fuel potential reported for similar coconut shell-based briquettes (Yirijor & Bere, 2024), but they would currently need careful, dry storage and gentle handling to avoid breakage during transport.

CONCLUSION

This study set out to convert two commonly discarded materials, coconut shell and waste paper, into a usable composite briquette fuel, and the results suggest that goal is achievable. Charred and uncharred coconut shell were successfully combined across five formulations using a fixed waste paper–starch binder, producing briquettes with low ash content (2.10–2.41%), moderate density (averaging 0.693 g/cm³), and combustion behaviour that improved as the proportion of charred material increased. The best-performing formulation, Sample E (60% charred, 20% uncharred coconut shell), combined the shortest ignition time (27 s) with the longest burning time (54 min), making it the most promising candidate among those tested. Moisture content and durability, however, remained higher and lower respectively than would be ideal for a premium household fuel, and water absorption was high enough that the briquettes would need protection from moisture during storage. These limitations point clearly to where future refinement should focus: extended drying, adjusted binder ratios, and higher compaction pressures. Even with these open questions, the briquettes produced here compare favourably with firewood in terms of cleanliness of combustion and consistency of size, and they demonstrate that agricultural and paper waste can be redirected into a renewable, low-ash household energy source, supporting both waste valorisation and reduced pressure on forest resources.

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