4rd INTERNATIONAL PARIS CONGRESS ON AGRICULTURE & ANIMAL HUSBANDRY

December 18-21, 2025
Paris, France

EDITOR
David John WORTLEY

ISBN: 979-8-89695-299-2

4th INTERNATIONAL PARIS CONGRESS ON AGRICULTURE & ANIMAL HUSBANDRY

December 18-21, 2025 –Paris, France

28.12.2025

Liberty Publishing House

Water Street Corridor New York, NY 10038

www.libertyacademicbooks.com

+1 (314) 597-0372

adopted by Mariam Rasulan

PROCEEDINGS BOOK

ISBN: 979-8-89695-299-2

CONGRESS ID

CONGRESS TITLE

4th INTERNATIONAL PARIS CONGRESS ON AGRICULTURE & ANIMAL HUSBANDRY

DATE AND PLACE

December 18-21, 2025 –Paris, France

ORGANIZATION

IKSAD INSTITUTE

EDITOR

David John WORTLEY

COORDINATOR

Samet KUŞKIRAN

PARTICIPANTS COUNTRY (11 countries)

TÜRKİYE, NETHERLANDS, AZERBAIJAN, ALBANIA, KOSOVO, KYRGYZ REPUBLIC, LIBYA, EGYPT, SAUDI ARABIA, INDIA, MOROCCO

Total Accepted Article: 66

Total Rejected Papers: 21

Accepted Article (Türkiye): 28

Accepted Article (Other Countries): 38

ISBN: 979-8-89695-299-2

ORGANIZING COMMITTEE MEMBER

Dr. Yusuf Hassan
Umaru Musa Yar'adua University

Dr. Mehmet Fırat BARAN
Siirt University, Faculty of Agriculture, Türkiye

Dr. Zubair ASLAM
University of Agriculture, Department of Agronomy, Pakistan

Dr. Nurlan Akhmetov
Ahmet Yesevi University, Kazakhstan

Dr. Yusuf Hassan
Umaru Musa Yar'adua University, Nigeria

Dr. Germán Martínez Prats
Universidad Juárez Autónoma de Tabasco, México

Dr. Rafael Ricardo Renteria Ramos
Universidad Abierta y a Distancia UNAD, Colombia

SCIENTIFIC ADVISORY COMMITTEE

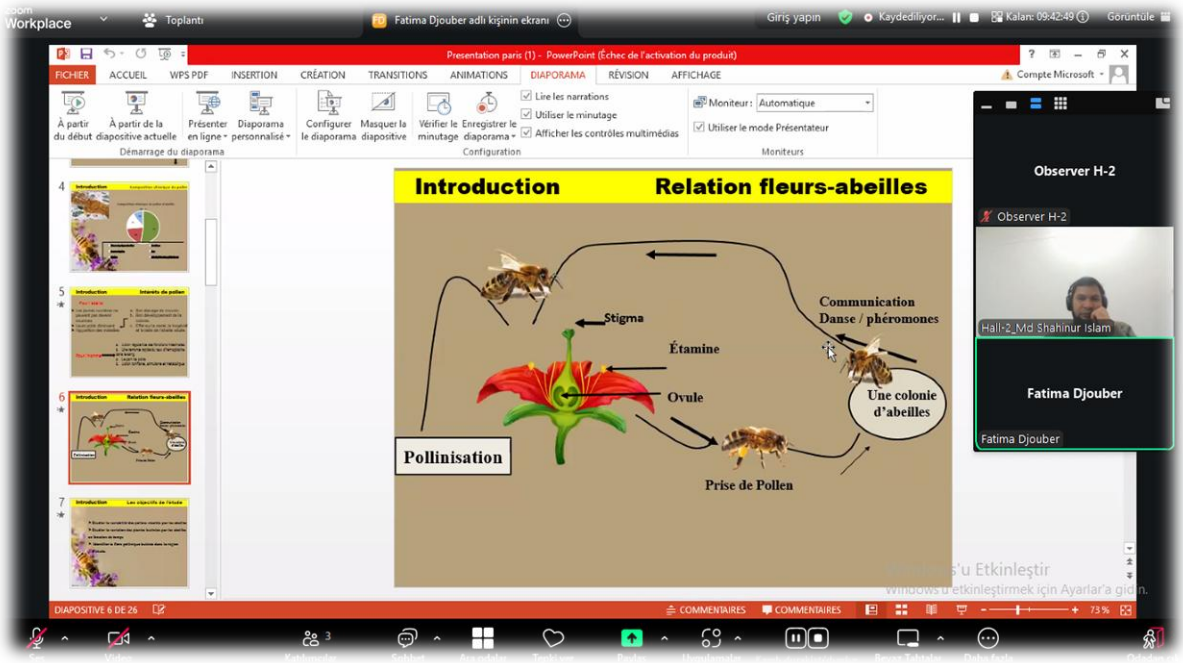
PHOTO GALLERY

PHOTO GALLERY

PHOTO GALLERY

PHOTO GALLERY

PHOTO GALLERY



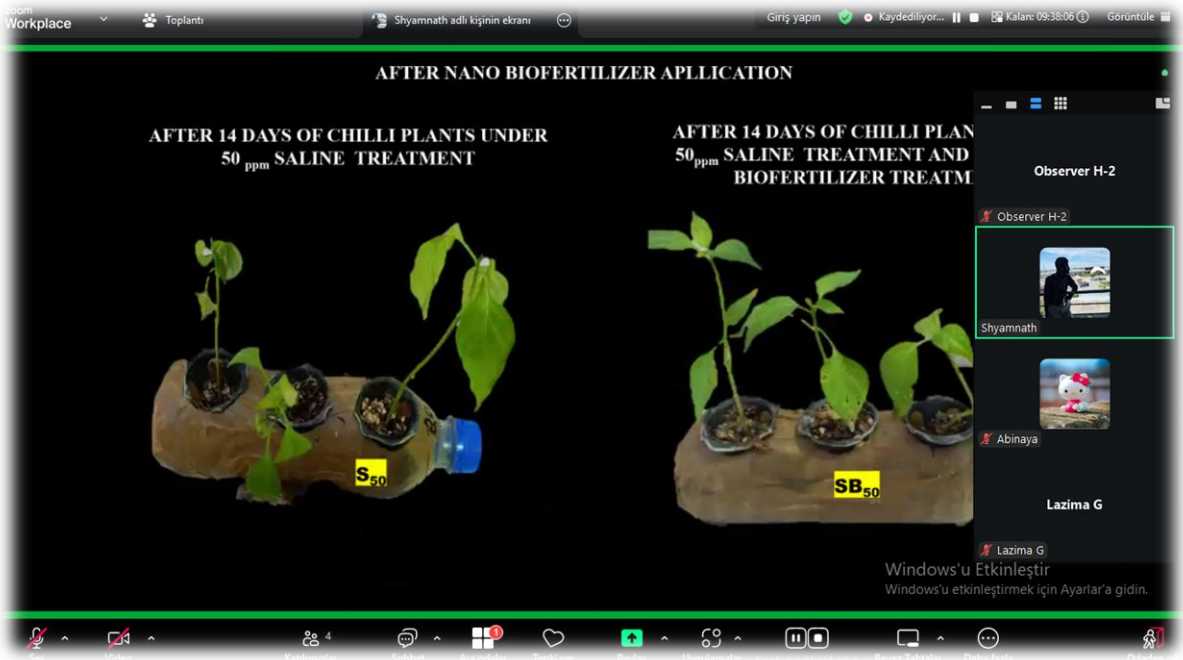


PHOTO GALLERY

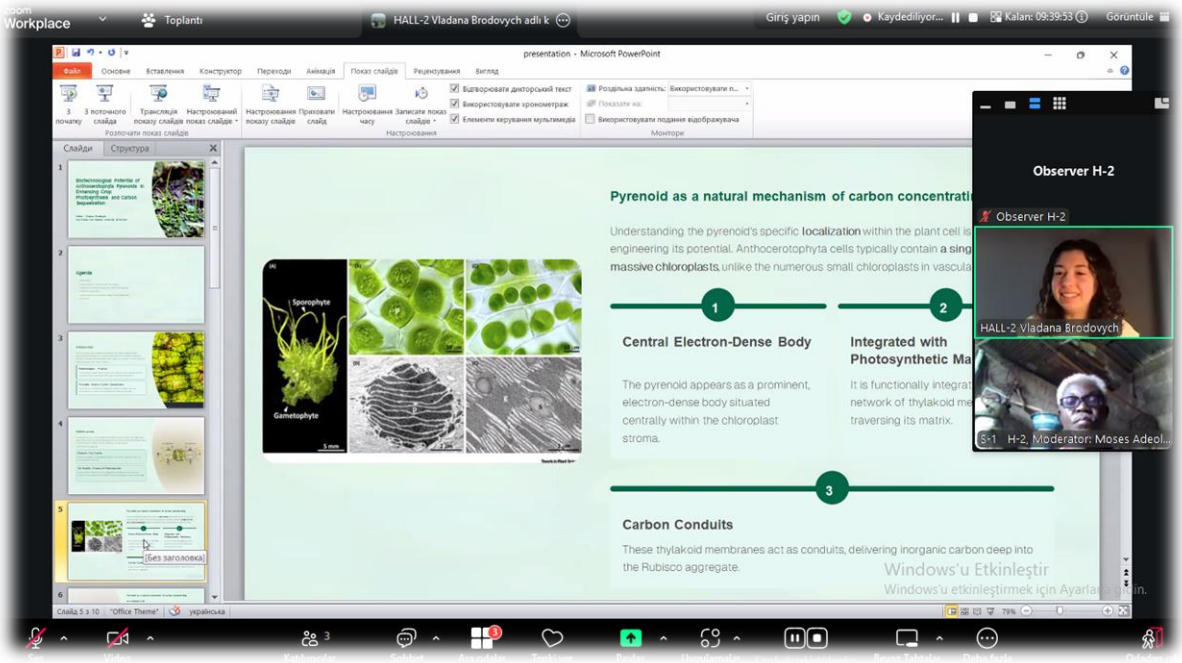
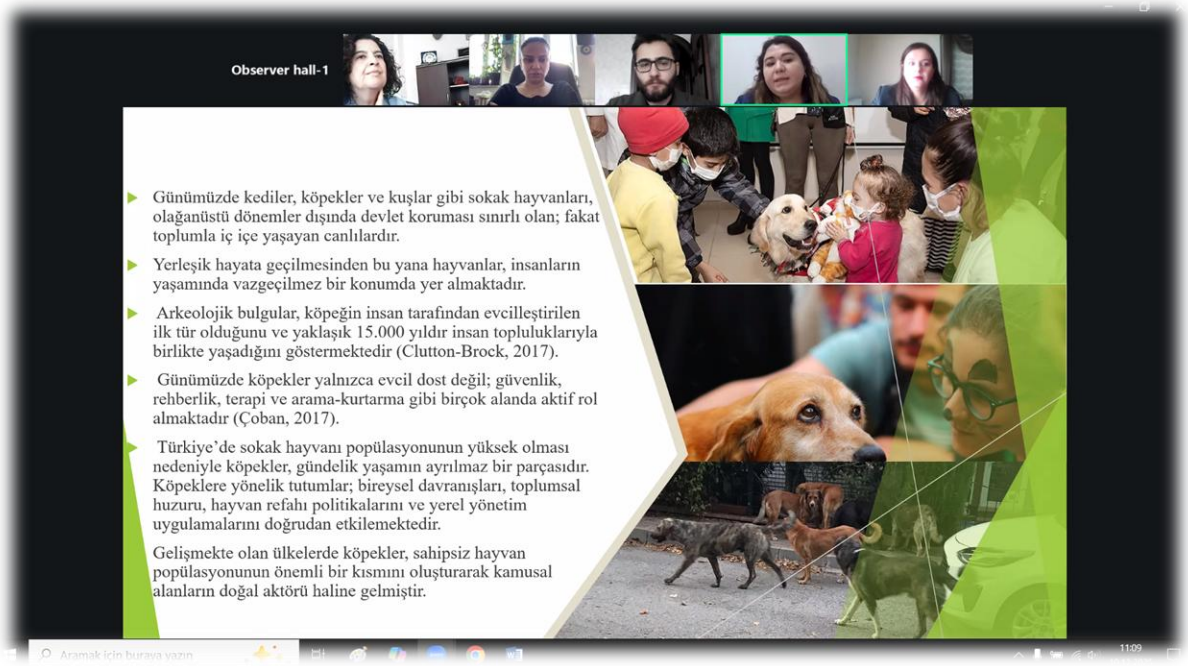
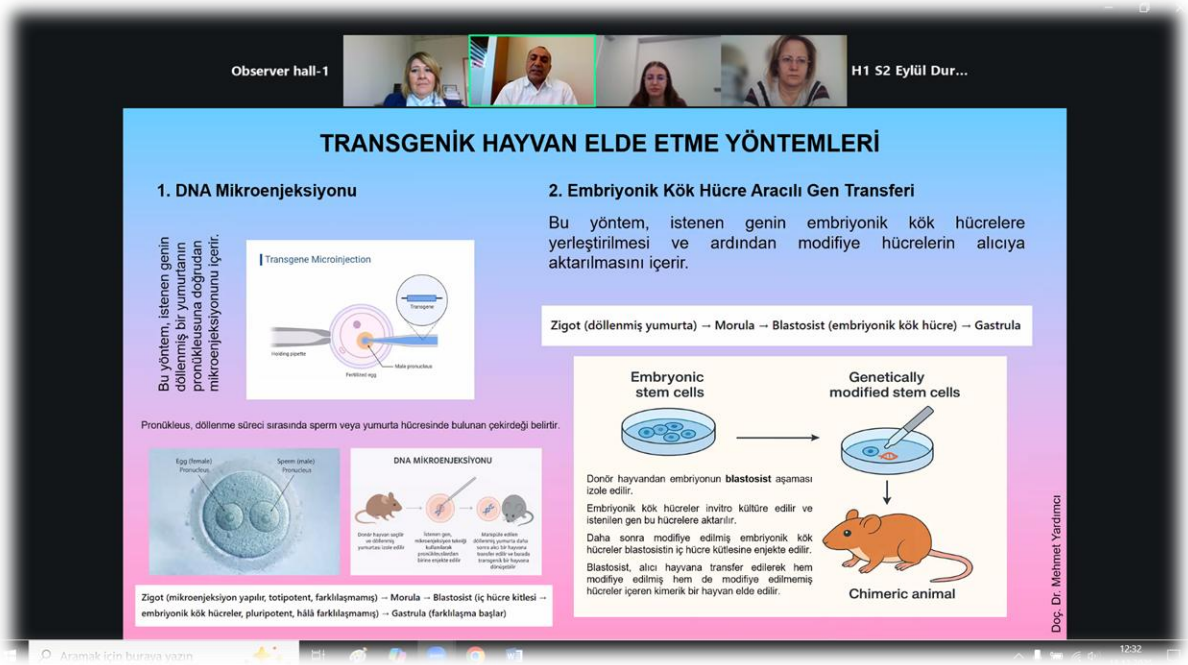


PHOTO GALLERY





4th INTERNATIONAL PARIS CONGRESS ON AGRICULTURE & ANIMAL HUSBANDRY

December 18-21 / Paris, FRANCE

CONFERENCE PROGRAM

Meeting ID: 897 0755 8402
Passcode: 123456

Join Zoom Meeting: https://us02web.zoom.us/j/89707558402?pwd=qTLqmqNIKb0zmkudxgzIaI1qdBH6y2.1

Participant Countries: (11)

Türkiye, Netherlands, Azerbaijan, Albania, Kosovo, Kyrgyz Republic, Libya, Egypt, Saudi Arabia, India, Morocco

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 özelliğini 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

- To be able to attend a meeting online, login via https://zoom.us/join site, enter ID "Meeting ID or Personal Link Name" and solidify the session.
- 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.

***

Zoom'a giriş yapmadan önce lütfen örnekteki gibi salon numaranızı, adınızı ve soyadınızı belirtiniz

Before you login to Zoom please indicate your hall number, name and surname

exp. H-5, Radmila Janičić

FACE TO FACE PRESENTATIONS

04.08.2025 / SESSION-1

	PARIS LOCAL TIME
	14 00 : 16 00

HEAD OF SESSION: Assoc. Prof. Dr. Hasan ÇİFTÇİ

AUTHORS	AFFILIATION	TOPIC TITLE
Assist. Prof. Dr. Özlem BEDİR **Prof. Dr. Deniz KORKMAZ** **Prof. Dr. Ömer KORKMAZ** **Prof. Dr. Aytaç AKÇAY** **Assist. Prof. Dr. Ayfer GÜLLÜ YÜCETEPE**	Harran University TÜRKİYE	AGE-DEPENDENT VARIATIONS IN SERUM AMH AND FSH LEVELS IN AWASSI EWES DURING AND OUTSIDE THE BREEDING SEASON

ONLINE PRESENTATIONS

18.12.2025 / HALL-1 / SESSION-1

PARIS LOCAL TIME	ANKARA LOCAL TIME
08 00 : 10 00	10 00 : 12 00

HEAD OF SESSION: Assoc. Prof. Dr. Fatma KAYAÇETİN

Authors	Affiliation	Presentation title
Assoc. Prof. Dr. Fatma KAYAÇETİN	Ankara University TÜRKİYE	PHENOLOGY, MORPHOLOGY, AND SEED YIELD OF TURNIP RAPE PURE LINES
Assoc. Prof. Dr. Fatma KAYAÇETİN	Ankara University TÜRKİYE	THE BIODIESEL FUEL CHARACTERISTICS OF BRASSICA RAPA SSP. OLEIFERA L. PURE LINES
Büşra İrem ÖZTEKİN **Prof. Dr. İmren KUTLU**	Eskişehir Osmangazi University TÜRKİYE	INVESTIGATION OF MORPHOLOGICAL, PHYSIOLOGICAL AND AGRONOMIC CHARACTERICTICS OF TRITICUM SPELTA AND TRITICUM MACHA HEXAPLOID WHEAT SPECIES
Recep BALKIÇ **Lokman ALTINKAYA** **Prof. Dr. Hamide GÜBBÜK**	Akdeniz University TÜRKİYE	EFFECTS OF IBA SOLUTIONS PREPARED WITH DIFFERENT ALCOHOL CONCENTRATIONS ON ROOTING IN PASSIFLORA EDULIS
Recep BALKIÇ **Lokman ALTINKAYA** **Prof. Dr. Hamide GÜBBÜK**	Akdeniz University TÜRKİYE	PASSIFLORA CULTIVATION IN TÜRKİYE: POTENTIAL, PRACTICES, AND FUTURE PERSPECTIVES
Assoc. Prof. Dr. Emine KAYA ALTOP **Sine KAYA**	Ondokuz Mayıs University TÜRKİYE	SYNERGISTIC EFFECTS OF PLANT HORMONES AND HERBICIDES
Assoc. Prof. Dr. Emine KAYA ALTOP **Sine KAYA**	Ondokuz Mayıs University TÜRKİYE	METAGENOMIC APPROACHES TO EXPLORE WEED-ASSOCIATED MICROBIOMES
Bilal Can ERKAN **Uğur GÜNEŞ** **Prof. Dr. Sevinç YEŞİLYURT**	Tekirdağ Namık Kemal University TÜRKİYE	ACCUMULATOR PLANTS AND MICROPLASTICS

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

ONLINE PRESENTATIONS

18.12.2025 / HALL-2 / SESSION-1

PARIS LOCAL TIME	ANKARA LOCAL TIME
08 00 : 10 00	10 00 : 12 00

HEAD OF SESSION: Prof. Dr. Ivan PAVLOVIĆ

Authors	Affiliation	Presentation title
Dr. Fatima DJOUBER-TOUDERT **Messaouda BELAID**	Mouloud Mammeri Tizi-Ouzou University ALGERIA	VARIABILITY OF POLLEN COLLECTED BY APIS MELLIFERA INTERMISSA BEES IN A MOUNTAINOUS REGION OF ALGERIA
Prof. Dr. Ivan PAVLOVIĆ	Scientific Institute of Veterinary Medicine SERBIA	BUMBLEBEE PARASITES TRANSMITTED TO HONEYBEES - Apicystis bombi
Md. Shahinur Islam **Md. Mosharraf Hosain** **Akira Yamanaka** **A. T. M. F. Islam**	Institute of Food and Radiation Biology, Atomic Energy Research Establishment BANGLADESH Yamaguchi University JAPAN	FIRST WINTER BREEDING LIFE HISTORY TRAITS OF THE PLAIN TIGER BUTTERFLY, DANAUS CHRYSIPPUS (LINNAEUS, 1758) (LEPIDOPTERA: DANAIDAE) THROUGHOUT THE WINTERING PERIOD ON SONADIA ISLAND, BANGLADESH
Gowridevi V **S. Suresh** **Murugesan Kamaraj**	SRM Institute of Science and Technology INDIA	EXPLORING PHYTASE PRODUCTION FROM MICROALGAE AND ITS INDUSTRIAL APPLICATIONS
LADACI Hadjer **LOUDJANI Farida** **LADOUALI Zineb** **ABDENNOUR Cherif**	Badji Mokhtar University ALGERIA	STUDY OF THE EFFECT OF CISTUS MONSPELIENSIS ON THE GENOMIC INTEGRITY OF SPERMATOZOA IN MALE RATS SUBJECTED TO LEAD TOXICITY
Saleh Amina Bakaro **Suleiman Ammar Muhammad** **Hassan Umar Ibrahim**	Federal University NIGERIA	ASSESSING SOIL PROPERTIES AND FEMALE FARMERS PERCEPTION OF GULLY EROSION CONTROL STRATEGIES IN KALTUNGO LOCAL GOVERNMENT AREA, GOMBE STATE NIGERIA
Samira EL AOUIDI **Zineb ELABOUDI** **Abdelmourhit LAISSAOUI** **Radouan SAADI** **Azzouz BENKDAD** **Zineb EL Mouridi**	Hassan II University MOROCCO National Center for Energy, Sciences and Nuclear Techniques (CNESTEN) MOROCCO	APPLICATION OF THE NORMALYSA TOOL FOR RADIATION DOSE CALCULATION IN THE SEMI-ARID MEKNES AGRICULTURAL REGION

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

ONLINE PRESENTATIONS

18.12.2025 / HALL-1 / SESSION-2

PARIS LOCAL TIME	ANKARA LOCAL TIME
$10^{30} : 12^{30}$	$12^{30} : 14^{30}$

HEAD OF SESSION: Prof. Dr. Aysun ÇAVUŞOĞLU

Authors	Affiliation	Presentation title
Assoc. Prof. Dr. Mehmet YARDIMCI	Tekirdağ Namık Kemal University TÜRKİYE	CURRENT APPROACHES, APPLICATIONS AND FUTURE PERSPECTIVES IN TRANSGENIC ANIMAL BIOTECHNOLOGY
Prof. Dr. Aysun ÇAVUŞOĞLU **Prof. Dr. Mehmet Erhan GÖRE**	Kocaeli University TÜRKİYE Bolu Abant İzzet Baysal University TÜRKİYE	THE STUDIES ON BOSCALID-RESISTANCE IN ALTERNARIA SPP. IN PLANT PROTECTION
Öykü DİVRİK **Assoc. Prof. Dr. Filiz ÜNAL** **Prof. Dr. Aysun ÇAVUŞOĞLU**	Eskişehir Osmangazi University TÜRKİYE Kocaeli University TÜRKİYE	IN VITRO EVALUATION OF ANTIFUNGAL POTENTIAL OF THREE PLANT ESSENTIAL OILS AGAINST BOTRYTIS CINEREA
Res. Assist. Ömer Ümit OKÇU **Prof. Dr. Nuray ÖZER**	Tekirdağ Namık Kemal University TÜRKİYE	EFFECTS OF FUNGICIDES ON NON-TARGET FUNGAL COMMUNITIES IN THE PLANT PHYLLOSPHERE
Assoc. Prof. Dr. Nihal KILIÇ **Kübra KOÇ**	Tekirdağ Namık Kemal University TÜRKİYE	HOST INTERACTIONS AND DAMAGE MECHANISMS OF ERIOPHYID MITES (ACARI: ERIOPHYIDAE)
Assoc. Prof. Dr. Nihal KILIÇ **Eylül Duru Yücel**	Tekirdağ Namık Kemal University TÜRKİYE	DRIED FRUIT MITE Carpoglyphus lactis: BIOLOGY, FOOD CONTAMINATION AND PROSPECTS FOR SUSTAINABLE CONTROL

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

ONLINE PRESENTATIONS

18.12.2025 / HALL-2 / SESSION-2

PARIS LOCAL TIME	ANKARA LOCAL TIME
10 30 : 12 30	12 30 : 14 30

HEAD OF SESSION: Amal Dagni

Authors	Affiliation	Presentation title
Amal Dagni Souraya Sakoui Abdelaziz Soukri Bouchra El Khalfi	Hassan II University MOROCCO	MICROENCAPSULATION OF DYSPHANIA AMBROSIOIDES ESSENTIAL OIL: AN EXAMPLE OF SUSTAINABLE VALORIZATION OF MOROCCAN NATURAL HERITAGE
Hasna ZAGGOUMI Said BOUDA Imane NEG Ibtissam MARDOUME Doha BELKACHACH Sonia MARGHALI Abdelmajid HADDIOUI	Sultan Moulay Slimane University MOROCCO Tunis El-Manar University TUNUSIA	BIOCHEMICAL AND ANTIMICROBIAL PROFILING OF CAROB (CERATONIA SILIQUA L.) ORGANS FROM MOROCCAN POPULATIONS
BENYAHOUB Rabie CHOUANA Toufik AZIB Salim	Kasdi Merbah University ALGERIA	INTEGRATED VALORIZATION OF QUINOA PROCESSING BY-PRODUCTS: FROM FUNCTIONAL FOOD INGREDIENTS TO BIOENERGY AND AGRICULTURAL APPLICATIONS
Mostafa OUHSSAINE Karim OUSSAID Sanaa CHERROUD Ayoub AINANE Tarik AINANE	Sultan Moulay Slimane University MOROCCO	FOAM-MAT DRYING: A SUSTAINABLE TECHNOLOGY TO REDUCE POST-HARVEST LOSSES AND ADD VALUE TO AGRI-FOOD PRODUCTS
S.Rubin thara N.Arshad ahamed E.Praveena R.Swathi R.SriArasuvasan K.Dinesh Rajan D.Aravindhan K.vaishnavi K.vijalakshmi	Bharath institute of higher education and research INDIA	HERBAL COSMETICS: TRENDS, SAFETY & EFFICACY
Ikram Elbezyouy Ilias Oussif Aabdousse Jamal Wahid Nadya	Sultan Moulay Slimane University MOROCCO	CHARACTERIZATION OF LEAVES, ROOTS, AND SOIL OF MEDICINAL AROMATIC PLANTS: SOIL-PLANT TRANSFER

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

ONLINE PRESENTATIONS

18.12.2025 / HALL-1 / SESSION-3

PARIS LOCAL TIME	ANKARA LOCAL TIME
13 00 : 15 00	15 00 : 17 00

HEAD OF SESSION: Assoc. Prof. Dr. Semin TOPALOĞLU PAKSOY

Authors	Affiliation	Presentation title
Assist. Prof. Dr. Mesut ÇOŞLU **Assoc. Prof. Dr. İlker ÜNAL**	Burdur Mehmet Akif Ersoy University TÜRKİYE	A MULTI-TEMPORAL ANALYSIS OF THE CORRELATION BETWEEN NDVI AND NDMI IN REMOTE SENSING-BASED PRECISION AGRICULTURE
Dr. Anıl Fırat FELEK **Prof. Dr. Faruk AKYAZI**	Ordu University TÜRKİYE	A REVIEW OF PRECISION MAPPING SYSTEMS FOR PLANT PARASITIC NEMATODE PROBLEMS: DIGITAL MAPPINGS OF AGRICULTURAL LANDS TO CREATE THE DATA FOR SITE-SPESIFIC NEMATODE INFESTATION AND MANAGEMENT DECISIONS
Assoc. Prof. Dr. Semin TOPALOĞLU PAKSOY **Dr. Emine Kokaçya DUVAN**	Çukurova University TÜRKİYE	EVALUATION OF TRANSITION EFFORTS OF TÜRKİYE TO ORGANIC AGRICULTURE: AN APPLICATION WITH THE MSD BASED RAWEC METHOD
Dr. Emine Kokaçya DUVAN **Assoc. Prof. Dr. Semin TOPALOĞLU PAKSOY**	Çukurova University TÜRKİYE	AGRICULTURAL BIODIVERSITY AND FOOD SECURITY: A COMPARISON WITH EXAMPLES FROM TURKEY AND THE WORLD
Assist. Prof. Dr. Hasan Selçuk ETİ	Tekirdağ Namık Kemal University TÜRKİYE	THE EFFECTS OF SUSTAINABLE AGRICULTURAL MARKETING ELEMENTS ON CONSUMER BEHAVIOR
Rashid Gasimov TAHIR	Institute of Soil Science and Agrochemistry AZERBAIJAN	ANALYSIS OF CERTAIN FACTORS CONTRIBUTING TO SOIL DEGRADATION PROCESSES IN THE SAATLI DISTRICT

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

ONLINE PRESENTATIONS

18.12.2025 / HALL-2 / SESSION-3

PARIS LOCAL TIME	ANKARA LOCAL TIME
13 00 : 15 00	15 00 : 17 00

HEAD OF SESSION: Fateme Asadi Touranlou

Authors	Affiliation	Presentation title
Kovendan M **S. Hemalatha**	B.S. Abdur Rahman Crescent Institute of Science and Technology INDIA	NANO-ENGINEERED ANTIMICROBIAL FORMULATION FOR THE CONTROL OF PLANT PATHOGEN
Abinaya V **Ranjani S** **S. Hemalatha**	B.S. Abdur Rahman Crescent Institute of Science and Technology INDIA	PHYTO-SYNTHESIS OF NANOPARTICLES TO CONTROL MULTIDRUG RESISTANCE GRAM NEGATIVE PATHOGENS
Lazima.G **Ranjani S** **S. Hemalatha**	B.S. Abdur Rahman Crescent Institute of Science and Technology INDIA	GREEN SYNTHESIS OF MELIA DUBIA MEDIATED SILVER NANOPARTICLES AND EXPLORING IT'S ANTIBACTERIAL PROPERTY IN MASTITIS PATHOGENS
Shyamnath. S **Sandhia.S** **Jeyanthi Rebecca.L**	Bharath Institute of Higher Education and Research INDIA	DEVELOPMENT OF NANO-BASED LIQUID BIOFERTILIZER FOR MITIGATION OF SALT STRESS IN CAPSICUM ANNUUM L AND SOLANUM MELONGENA PLANTS
Fedwa BEGHDADI **El-Hadj DRICHE**	Hassiba Benbouali University ALGERIA	ISOLATION OF SAHARAN ACTINOBACTERIA FOR BIOLOGICAL CONTROL AGAINST PHYTOPATHOGENS: TOWARDS SUSTAINABLE AGRICULTURE
Fedwa BEGHDADI **El-Hadj DRICHE**	Hassiba Benbouali University ALGERIA	ENVIRONMENTAL AND CONSUMER HEALTH RISKS ASSOCIATED WITH MYCOTOXINS PRODUCED BY PHYTOPATHOGENIC FUNGI
Fateme Asadi Touranlou	Mashhad University of Medical Sciences IRAN	STUDYING THE EFFECT OF HEMATITE AND TITANIUM DIOXIDE NANOPARTICLES ON REDUCING CADMIUM LEVELS IN WHEAT GRAIN: A REVIEW

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

ONLINE PRESENTATIONS

19.12.2025 / HALL-1 / SESSION-1

PARIS LOCAL TIME	ANKARA LOCAL TIME
08 00 : 10 00	10 00 : 12 00

HEAD OF SESSION: Prof. Dr. Nurinisa ESENBUĞA

Authors	Affiliation	Presentation title
Assist. Prof. Dr. Serpil AYGÖRMEZ **Prof. Dr. Mushap KURU** **Assoc. Prof. Dr. Mustafa MAKAV**	Kafkas University TÜRKİYE	CHANGES IN SERUM PARAOXONASE-1 ACTIVITY DURING ESTRUS IN PROGESTERONE-BASED SYNCHRONIZED GURCU GOATS DURING PERIODS BREEDING SEASON AND NON-BREEDING SEASON
Prof. Dr. Ömer Cevdet BİLGİN **Prof. Dr. Nurinisa ESENBUĞA**	Atatürk University TÜRKİYE	USE OF CANONICAL CORRELATION ANALYSIS IN ASSESSING THE RELATIONSHIP BETWEEN BODY MEASUREMENTS AND CARCASE CHARACTERISTICS IN AWSSI SHEEP
Prof. Dr. Nurinisa ESENBUĞA **Prof. Dr. Ömer Cevdet BİLGİN**	Atatürk University TÜRKİYE	COMPARISON OF LACTATION CURVE MODELS IN TUJ SHEEP
Assoc. Prof. Dr. Caner ÖZTÜRK **Assoc. Prof. Dr. Neşe Hayat AKSOY** **Lect. Dr. Erkan ÖZKAN** **Res. Assist. Ramazan ARSLAN**	Aksaray University TÜRKİYE	IMPACT OF MELOXICAM ON OXIDATIVE STATUS IN REPRODUCTIVE TISSUES OF MALE RATS
Cansu DÖLEK **Prof. Dr. Mücahit Taha ÖZKAYA**	Çukurova University TÜRKİYE Ankara University TÜRKİYE	A DIFFERENT EXTRACTION PROCEDURE IN OLIVE OIL PRODUCTION
Res. Assist. Dr. Haydar KÜPLEMEZ **Prof. Dr. Fatih SEYİS**	Recep Tayyip Erdoğan University TÜRKİYE	VOLATILE COMPOUNDS OF Hypericum orientale
Res. Assist. Dr. Haydar KÜPLEMEZ **Prof. Dr. Fatih SEYİS**	Recep Tayyip Erdoğan University TÜRKİYE	DETERMINATION OF MORPHOGENETIC VARIABILITY ON VOLATILE COMPOUNDS OF Rhododendron caucasicum
Assoc. Prof. Dr. Davut BAYRAM **Hürü Ceyda TÜM**	Erciyes University TÜRKİYE	BEHAVIORS AND ATTITUDES OF ACADEMIC AND ADMINISTRATIVE STAFF AND UNIVERSITY STUDENTS TOWARDS DOGS

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

ONLINE PRESENTATIONS

19.12.2025 / HALL-2 / SESSION-1

PARIS LOCAL TIME	ANKARA LOCAL TIME
08 00 : 10 00	10 00 : 12 00

HEAD OF SESSION: MD. Kabir Hossain

Authors	Affiliation	Presentation title
Jayashree Chowdhury **Bandana Chowdhury** **Sourav Deuri**	Handique Girls' College INDIA Gauhati University INDIA Handique Girls' College INDIA	INDIGENOUS ALDER (ALNUS NEPALENSIS) BASED AGROFORESTRY SYSTEMS AMONG TRIBAL COMMUNITIES OF NAGALAND: A PATHWAY TO SUSTAINABLE LAND USE
MD. Kabir Hossain	Rajendrapur Cantonment Public School and College at Rajendrapur BANGLADESH	ASSESSING THE HETEROGENEOUS EFFECTS OF RAINFALL AND IRRIGATION ON AGRICULTURAL PRODUCTIVITY IN BANGLADESH: TAKEAWAYS FOR CLIMATE SMART AGRICULTURE
Oluwadamilola Peace AGOI **Moses Adeolu AGOI** **Samuel Olayiwola AJAGA** **Oluwanifemi Opeyemi AGOI**	Federal University of Agriculture Abeokuta NIGERIA Lagos State University of Education NIGERIA Obafemi Awolowo University NIGERIA	VIRTUAL REALITY AS A TOOL FOR FARMER TRAINING IN BIODIVERSITY-FRIENDLY PRACTICES
Ilham Chennak **Lamiaa Belasri** **Mohammed El Krati** **Samah Ait Benichou**	Chouaïb Doukkali University MOROCCO	ASSESSMENT OF THE EFFECTS OF STABILIZED MUNICIPAL ORGANIC WASTE COMPOSTS ON TOMATO (SOLANUM LYCOPERSICUM L.) GROWTH AND ENZYMATIC ACTIVITIES OF PEROXIDASE AND SUCCINATE DEHYDROGENASE
Vladana Brodovych	Ivan Franko National University UKRAINE	BIOTECHOLOGICAL POTENTIAL OF ANTHOCEROTOPHYTA PYRENOIDS IN ENHANCING CROP PHOTOSYNTHESIS AND CARBON SEQUESTRATION
Fase O.B **Oyekale, J. I**	Department of Crop Production Technology, School of Agriculture NIGERIA	CORRELATION AND HERITABILITY OF MORPHOLOGY AND YIELD CHARACTERISTICS IN NERICA RICE GENOTYPES

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

ONLINE PRESENTATIONS

19.12.2025 / HALL-1 / SESSION-2

PARIS LOCAL TIME	ANKARA LOCAL TIME
10 30 : 12 30	12 30 : 14 30

HEAD OF SESSION: Mouassa Bochra

Authors	Affiliation	Presentation title
Md. Rafiqul Islam Tridip Roy Mohammad Lokman Ali Sabrina Akter Rinju Sudipta Kumar Nag Tawhidur Rahman	Patuakhali Science and Technology University BANGLADESH Water Development Board BANGLADESH	ASSESSMENT OF THE PRODUCTION PERFORMANCE OF INDIAN MAJOR CARP ROHU (LABEO ROHITA) WITH TILAPIA (OREOCHROMIS NILOTICUS) ON CAGE CULTURE SYSTEM IN SOUTHERN BANGLADESH
Mouassa Bochra	Chadli Benjdid University ALGERIA	HISTOLOGICAL AND MORPHOLOGICAL ASSESSMENT OF GONADAL MATURATION IN THE GILTHEAD SEA BREAM (SPARUS AURATA) FROM ALGERIAN WATERS
Mouassa Bochra	Chadli Benjdid University ALGERIA	HISTOLOGICAL CHARACTERIZATION OF GONADAL DEVELOPMENT IN PENAEUS KERATHURUS: IMPLICATIONS FOR AQUACULTURE IN ALGERIA
Mousumi Saha Md. Ataur Rahman Md. Tuhinur Rahman Md. Tasmir Rayan Labib Robius Sani Sadi Md. Farhan Hasan	Bangabandhu Sheikh Mujibur Rahman Agricultural University BANGLADESH Sheikh Mujibur Rahman Agricultural University BANGLADESH	A CASE REPORT ON THE SUCCESSFUL MANAGEMENT OF OBSTRUCTIVE UROLITHIASIS IN GOATS USING TUBE CYSTOSTOMY
ALI Hamada	Hassan II University MOROCCO	USE OF NATURAL BIORESOURCES AS COAGULANTS TO TREAT WATER RICH IN TOXIC DYES
Otegbeye-Lawal Adenike Atinuke	Science Laboratory Technology, Federal Polytechnic NIGERIA	EVALUATING THE RESPONSE OF SOIL MICROORGANISMS TO PESTICIDES EXPOSURE IN FARMLANDS

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

ONLINE PRESENTATIONS

19.12.2025 / HALL-2 / SESSION-2

PARIS LOCAL TIME	ANKARA LOCAL TIME
$10^{30} : 12^{30}$	$12^{30} : 14^{30}$

HEAD OF SESSION: Md. Musabbir Hossain Shoun

Authors	Affiliation	Presentation title
Raisa, Ranjani S S. Hemalatha	B.S. Abdur Rahman Crescent Institute of Science and Technology INDIA	DEVELOPMENT OF ECO-FRIENDLY FOOD WRAPPERS TO INCREASE THE SHELF LIFE IN FRUITS
Tope James Blessing Mayowa	Newland Polytechnic NIGERIA Kwara State University NIGERIA	PROCESSING AND ORGANOLEPTIC ASSESSMENT OF SACCHAROMYCES CEREVISIAE-FERMENTED TIGER NUT (CYPERUS ESCULENTUS) WINE
Md. Musabbir Hossain Shoun	Khulna University BANGLADESH	ESTIMATION OF VARIABILITY AND IDENTIFICATION OF SUPERIOR GENOTYPES IN SODIUM AZIDE (SA)-INDUCED RICE MUTANTS (M3)
Loga Sreeyaa R K Ranjani S S. Hemalatha	B.S. Abdur Rahman Crescent Institute of Science and Technology INDIA	NELUMBO NUCIFERA MEDIATED SILVER NANOPARTICLES: A SUSTAINABLE STRATEGY TO CONTROL DERMATOPHYTES
M Annish Shabiya S. Hemalatha Ranjani S	B.S. Abdur Rahman Crescent Institute of Science and Technology INDIA	PLANT-DERIVED POLYHERBAL NANOTHERAPY FOR TARGETING S. MUTANS–INDUCED DENTAL CARIES: AN INTEGRATED IN SILICO AND IN VITRO APPROACH

All participants must join the conference 10 minutes before the session time.
Every presentation should last not longer than 10-12 minutes. Kindly keep your cameras on till the end of the session.

CONTENTS

AGE-DEPENDENT VARIATIONS IN SERUM AMH AND FSH LEVELS IN AWASSI EWES DURING AND OUTSIDE THE BREEDING SEASON

Özlem BEDİR

Harran University, Faculty of Veterinary Medicine, Department of Histology and Embryology, Şanlıurfa, Turkiye

ORCID ID: https://orcid.org/0000-0002-2558-1599

Deniz KORKMAZ

Harran University, Faculty of Veterinary Medicine, Department of Histology and Embryology, Şanlıurfa, Turkiye

ORCID ID: https://orcid.org/0000-0002-1257-4816

Ömer KORKMAZ

Harran University, Faculty of Veterinary Medicine, Department of Obstetrics and Gynecology, Şanlıurfa, Türkiye

ORCID ID: https://orcid.org/0000-0001-5179-2181

Aytaç AKÇAY

Ankara University, Faculty of Veterinary Medicine, Department of Animal Science and Nutrition, Department of Veterinary Biostatistics, Ankara, Türkiye

ORCID ID: https://orcid.org/0000-0001-6263-5181

Ayfer GÜLLÜ YÜCETEPE

Harran University, Faculty of Veterinary Medicine, Department of Microbiology, Şanlıurfa, Türkiye

ORCID ID: https://orcid.org/0000-0002-9842-3305

ABSTRACT

Introduction and Purpose: Reproductive efficiency in sheep has a direct impact on flock sustainability and productivity. Identifying reliable hormonal markers is essential for evaluating ovarian activity and selecting high-fertility females. Anti-Müllerian hormone (AMH), secreted by granulosa cells of preantral and small antral follicles, reflects the ovarian reserve, while follicle-stimulating hormone (FSH), produced by the anterior pituitary, regulates follicle recruitment and growth. Age, reproductive status, and season may alter their physiological levels. However, limited data exist on these parameters in native Awassi (İvesi) ewes. This study aimed to determine age-dependent variations in serum AMH and FSH levels during and outside the breeding season. This study represents the preliminary phase of a TÜBİTAK 1001-funded project investigating molecular and histological aspects of ovarian function in Awassi ewes.

Materials and Methods: Blood samples were obtained from 200 clinically healthy female Awassi sheep, categorized into three age groups: 1 week old, 6 months old, and 1–5 years old (n = 20 per group). Sampling was conducted during both the breeding (autumn–winter) and non-breeding (spring–summer) seasons. Serum AMH and FSH levels were measured using ELISA. Statistical analyses were performed using t-tests and the Kruskal–Wallis test ($p < 0.05$).

Results: No significant differences were detected between 1-week-old and 6-month-old animals. During the breeding season, both AMH and FSH levels varied significantly among age groups ($p < 0.001$), with the highest concentrations observed in 5-year-old ewes. AMH was also elevated in the 1-, 2-, and 5-year-old groups compared to the 3- and 4-year-old groups. In the non-breeding season, hormone levels remained relatively stable ($p > 0.05$).

Discussion and Conclusion: Age and reproductive season have a significant influence on circulating AMH and FSH levels in Awassi ewes. Higher concentrations during the breeding season may indicate increased follicular activity and ovulatory potential. The stability of hormone levels outside the breeding season supports photoperiodic control of reproduction. AMH and FSH appear to be promising non-invasive biomarkers for improving reproductive management and selection strategies in sheep breeding programs.

Key Words: Awassi ewe; AMH; FSH; Breeding season; Ovarian activity

PLANT-DERIVED POLYHERBAL NANOTHERAPY FOR TARGETING *S. MUTANS*–INDUCED DENTAL CARIES: AN INTEGRATED *IN SILICO* AND *IN VITRO* APPROACH

M Annish Shabiya

School of Life Sciences, B. S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai, Tamil Nadu, India.

S. Hemalatha

School of Life Sciences, B. S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai, Tamil Nadu, India.

Ranjani S

School of Life Sciences, B. S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai, Tamil Nadu, India.

Abstract

Green nanotechnology offers a sustainable method for engineering nanoformulations using plant-derived reducing agents. In this study, a polyherbal extract was employed as both a reducing and stabilizing agent to synthesize silver nanoemulsion (PHNE) and silver nanoparticles (PHNPs). Formulated nanoemulsion was characterized by using UV–Visible spectroscopy for surface plasmon resonance, X-ray diffraction, and FESEM for crystalline structure and morphology, EDAX for elemental composition, DLS and zeta potential for particle size distribution and colloidal stability, and FTIR to identify functional groups involved in nanoparticles capping. Phytoconstituents in the extract were profiled by using LC–MS, and the identified molecules were screened for drug-likeness using Lipinski's Rule of Five and SwissADME, while toxicity was evaluated with ProTox-II. Selected bioactive compounds were docked against *Streptococcus mutans* target proteins by using PyRx, and key binding interactions were visualized in Discovery Studio Visualizer to infer possible anti-caries mechanisms. Antioxidant activity (DPPH assay) and Anti-inflammatory effects (protein denaturation inhibition) of the crude extract, PHNPs, and PHNE were comparatively assessed. The nanoemulsion displayed superior bioactivity compared to both nanoparticles and the polyherbal extract. Future studies will extend these findings to antibacterial assays using clinical oral isolates from dental patients to validate therapeutic applicability. Overall, this integrated *in silico* and *in vitro* strategy supports the potential of polyherbal-mediated green nanoformulations for managing *S. mutans*-associated dental caries and broader biomedical applications. In future nanoemulsion incorporated dental care products will be development for oral health care.

Keywords: Eco-friendly synthesis, Plant-based polyherbal extracts, Silver nanoformulations, Computational docking, Anti-oxidant and Anti-inflammatory.

NELUMBO NUCIFERA MEDIATED SILVER NANOPARTICLES: A SUSTAİNABLE STRATEGY TO CONTROL DERMATOPHYTES

Loga Sreeyaa R K

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

Ranjani S

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

S. Hemalatha

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

Abstract

Nelumbo nucifera is an aquatic plant widely distributed in Asia and known for the cultural, nutritional and medical benefits. The flowers are enriched with bioactive substances including alkaloids, flavonoids and fatty acids that holds antioxidant, antibacterial and antifungal properties. Phytocompounds are known to rupture fungal cell membranes and prevent the growth of dermatophytes, namely *Trichophyton rubrum* and *Microsporum canis.* Nanoparticles due to their small size (1 to 100 nm) and high surface area, can easily penetrate through the fungal cell wall and cause cellular disruption compared to the larger molecules present in the floral extract. This study focuses on the synthesis of silver nanoparticles by using *Nelumbo nucifera* floral extract for antifungal applications. The resulting nanoparticles were purified and characterized using UV-Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR) and Energy Dispersive X-ray (EDAX) analysis. A distinct surface plasmon resonance peak near 400 nm confirmed the synthesis of silver nanoparticles, FTIR revealed phenolic and flavonoid groups responsible for reduction and natural capping, while EDAX validated elemental silver composition in the final nanoparticle's matrix. Nanoparticles effectively controlled the growth of *Trichophyton rubrum* and *Microsporum canis* even at the lower concentration of 25 µg/mL on comparison with fluconazole till the 8^{th} day of treatment. The floral extract incorporated nanoparticles could pave a way for the development of topical antifungal creams and ointments for treating fungal infections.

Keywords: *Nelumbo nucifera,* Silver Nanoparticles, Antifungal, Dermatophytes.

ESTIMATION OF VARIABILITY AND IDENTIFICATION OF SUPERIOR GENOTYPES IN SODIUM AZIDE (SA)-INDUCED RICE MUTANTS (M3)

Md. Musabbir Hossain Shoun

Bachelor of Science in Agriculture Khulna University, Bangladesh.

Abstract:

The development of mutant populations, accompanied by their subsequent characterization, presents a substantial opportunity to isolate genotypes by exhibiting specific desirable traits of interest. Although development of blast-resistant rice varieties is an area of priority, there is a significant dearth of knowledge on the comprehensive assessment for the induced mutants in terms of disease resistance and important agronomic traits under one framework in multiple generations level. An investigation was carried out to assess the diversity among the 100 mutants (M3) to select superior genotypes based on their phenotypic characteristics and the genetic control on the expression of the traits. The experiment was laid out in a randomized complete block design (RCBD) with three replications. This selection was carried out depending on the genetic variation arising from treatment with sodium azide. Data collected on 17 quantitative traits from three randomly selected plants from each plot. The investigation revealed significant genetic and phenotypic variability among the mutant lines, with traits like grain yield hill^{-1}, total tillers hill^{-1}, effective tillers hill^{-1}, filled grains panicle^{-1} and straw yield hill^{-1} showing high heritability and genetic advance. Grain yield was positively and significantly correlated with plant height, panicle length, total grains panicle^{-1}, filled grains panicle^{-1} and straw yield hill^{-1}. PCA revealed five principal components, with the first two accounting for over 52% of the total variance, highlighting the yield contributing traits like plant height, panicle length, flag leaf length, and grain yield mainly have in tillering capacity and biomass potential as primary selection criteria. Ward's Agglomerative clustering grouped the mutants into two major clusters and the genotypes with better performance were accumulated in cluster II. Finally, a total of seven elite genotypes were selected based on their greater performance in plant height, panicle length, primary branches panicle^{-1}, flag leaf length, filled grains panicle^{-1}, grain yield hill^{-1}, and straw yield hill^{-1} for further breeding purposes. Overall, the findings underscore the efficacy of sodium azide in creating genetic diversity and its potential to develop high-yielding rice varieties.

PROCESSING AND ORGANOLEPTIC ASSESSMENT OF *SACCHAROMYCES CEREVISIAE*-FERMENTED TIGER NUT (*CYPERUS ESCULENTUS*) WINE

Tope James Ogidi

Newland Polytechnic, Ilorin, Kwara, Nigeria, Department of Science Laboratory Technology

ORCID: 0009-0009-0925-262X

Blessing Mayowa Sanni

Kwara State University, Department of Microbiology

ORCID: 0009-0000-6396-6548

Abstract

The need for different, functional beverages has led to increased interest in the development of non-fruit-based wines using locally sourced and health enhancing substrates. This study explores the possibility of producing wine from tiger nut (*Cyperus esculentus*) through fermentation using *Saccharomyces cerevisiae*. Tiger nut (*Cyperus esculentus*) was selected for their carbohydrate and protein content. The tiger nuts were soaked, blended and filtered to extract the tiger nut milk. The extracted tiger nut milk was pasteurized. The pasteurized tiger milk was inoculated with the cultures of *S. cerevisiae*, and fermentation was carried out at 30°C for 14 days. Samples were taken periodically to evaluate pH, alcohol content, reducing sugar concentration, microbial viability, and sensory characteristics. The results showed that the fermentation of tiger nut milk produced a wine with moderate alcohol content (10%), the pH reduced from 7.5-3.8, yeast count reduced from 2.0 x 10^3 cfu/ml (day 1) to 1.0 x 10^2 cfu/ml (day 14), the sugar content reduced from 20.0 °Brix (day 1) to 3.0 °Brix (day 14). Sensory evaluation revealed that the wine was generally acceptable in terms of aroma, taste, and mouthfeel. The overall sensory evaluation acceptability was 7.5 on the scale of 10. This study showed that tiger nut when properly processed and fermented, can serve as a viable substrates for wine production. The study offers a novel approach to enhancing both the sensory and functional properties of non-conventional wines, particularly in Nigeria, where grapes are not readily cultivated.

Keywords: Beverages, reducing sugar, *Saccharomyces cerevisiae*, alcohol content.

DEVELOPMENT OF ECO-FRIENDLY FOOD WRAPPERS TO INCREASE THE SHELF LIFE IN FRUITS

Raisa, Ranjani S

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

S. Hemalatha

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

Abstract

Fruits are highly perishable and tend to lose quality rapidly after harvesting due to moisture loss, microbial spoilage, and respiration. To minimize these postharvest losses, edible coatings have emerged as an eco-friendly alternative to synthetic packaging. Pectin, a natural biopolymer extracted from citrus peels, exhibits excellent film-forming ability and is safe for food applications. Pectin-based edible coatings help preserve the freshness, firmness, and colour of fruits by regulating gas exchange and inhibiting microbial growth. The functional properties of pectin can be further enhanced by blending it with other natural compounds or incorporating essential oils. In this study, pectin was extracted from citrus fruits and characterization techniques namely FTIR and HPLC were employed to analyze the structural, functional, and compositional properties of the extracted and blended pectin. Extracted pectin effectively controlled the growth of food borne pathogens which were isolated from spoiled fruits and vegetables. This study highlights the potential of pectin-based edible coatings in extending the shelf life of fruits. These findings emphasize the feasibility of replacing synthetic preservatives with safe and biodegradable coating materials in preservation of fruits and vegetables. The approach provides a promising route toward sustainable postharvest management and reduced environmental impact in the food packaging sector.

Keywords: Pectin, Edible coating, Shelf life, Fruits, Biopolymer, Food preservation

EVALUATING THE RESPONSE OF SOIL MICROORGANISMS TO PESTICIDES EXPOSURE IN FARMLANDS

Otegbeye-Lawal

Science Laboratory Technology, Federal Polytechnic, Ilaro, Nigeria

Adenike Atinuke

Science Laboratory Technology, Federal Polytechnic, Ilaro, Nigeria

ORCID iD: 0009-0008-3789-2838

ABSTRACT

Soil microorganisms play essential roles in nutrient cycling, organic matter decomposition, soil fertility, and overall ecosystem stability. However, the widespread and often indiscriminate use of pesticides in agriculture has raised concerns about their potential impacts on soil microbial diversity and function. This study evaluates the response of soil microbial populations to pesticide exposure in farmland soils, focusing on changes in microbial load, community structure, and enzymatic activities. Soil samples were collected from pesticide-treated and untreated (control) plots, followed by microbial enumeration using standard culture-dependent techniques and characterization of microbial diversity. Findings indicate that pesticide exposure can significantly reduce total heterotrophic bacterial and fungal counts, alter the abundance of beneficial microbes such as nitrogen fixers, and suppress key soil enzymes involved in nutrient cycling. The degree of impact varied with pesticide type, concentration, and duration of exposure. This study highlights the need for sustainable pesticide management practices to protect soil microbial health and maintain long-term agricultural productivity.

Keywords: Soil microorganisms, agroecosystems, soil enzyme activity, pesticides, microbial diversity

USE OF NATURAL BIORESOURCES AS COAGULANTS TO TREAT WATER RICH IN TOXIC DYES

ALI Hamada

Laboratory of Physical-Chemistry, Materials and Catalysis, Faculty of Sciences Ben M'Sik,

Hassan II University of Casablanca, Morocco

Abstract

Ecosystems are experiencing imbalance due to water pollution. Wastewater contains hazardous pollutants such as dyes that require appropriate treatment. These are often highly toxic depending on their content in the water. In this study, electrocoagulation with aluminum electrodes combined with biocoagulants was used to treat crystal violet dye, which is toxic to humans and living beings. Based on a Box-Behnken experimental design (BBD) and reaction parameters such as pH, current density, and electrolysis time, a dye removal rate of 96% was observed. The study demonstrated the potential of bioresources for the removal of toxic dyes, with very low energy costs and better performance, thus opening up prospects for sustainable development.

Key words: electrocoagulation, crystal violet, biocoagulant, Dye, BBD.

A CASE REPORT ON THE SUCCESSFUL MANAGEMENT OF OBSTRUCTIVE UROLITHIASIS IN GOATS USING TUBE CYSTOSTOMY

Mousumi Saha

Md. Ataur Rahman

Md. Tuhinur Rahman

Md. Tasmir Rayan Labib

Robius Sani Sadi

Md. Farhan Hasan

Department of Surgery and Radiology, Department of Pathobiology Department of Medicine, Faculty of Veterinary Medicine and Animal Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur 1706.

Abstract

This case report discusses obstructive urolithiasis, a condition in which insoluble minerals and salt stones develop and accumulate in the bladder or urethra, leading to the obstruction of the urinary tract. Male ruminants are more susceptible to this condition due to their anatomically different urethral tract shape. Urolithiasis is a significant risk factor for animal mortality, causing enormous economic losses in the livestock industry. The most popular form of treatment for obstructive urolithiasis is surgical tube cystostomy, which involves diverting urine through a catheter inserted from the bladder and leaving through the abdominal wall. This case report describes the successful surgical procedure of tube cystotomy in a one-year-old crossbred male goat and the outcome of the surgery. The goat had been straining during urination for ten days, and several stones were found in its bladder during an ultrasound examination. The surgery was performed after the owner gave consent, and the patient was administered anesthesia, followed by a 1.5-inch incision on the left side of the left rudimentary teat. The procedure involved inserting a Foley catheter, which was sutured at different locations on the ventral abdomen to avoid any disruption during urine flow. Postoperative medication included an anti-inflammatory drug, antihistaminic, and antibiotic for seven days. The surgery was successful, and the goat made a full recovery, demonstrating that tube cystotomy can be an effective treatment for obstructive urolithiasis in male goats.

Key Words: Urolithiasis, Tube cystostomy, Surgical management

HISTOLOGICAL CHARACTERIZATION OF GONADAL DEVELOPMENT IN PENAEUS KERATHURUS: IMPLICATIONS FOR AQUACULTURE IN ALGERIA

Mouassa Bochra

University Chadli benjdid, el Tarf, Algeria Researche lab: Epidemiological surveillance, health, production, reproduction, experimentation, and cellular therapy of domestic and wild animals

ORCID ID: https://orcid.org/ 0009-0007-3766-1274

Abstract

Crustacean farming in Algeria, particularly shrimp farming, is an emerging activity with significant potential due to the country's long coastline and favorable environmental conditions. The main species include the Mediterranean white shrimp (*Penaeus kerathurus*), the giant tiger prawn (*Penaeus monodon*), and the Pacific white shrimp (*Litopenaeus vannamei*), valued for their rapid growth and profitability. Shrimp feeding combines natural sources (phytoplankton, zooplankton) and enriched pellets, while reproduction in captivity requires precise control of conditions (temperature, salinity) and facilities such as hatcheries. Although challenges remain regarding infrastructure and training, this sector represents a promising economic opportunity to diversify aquaculture and meet both local and international demand.

Keywords: Crustaceans, farming, Algeria, shrimp.

HISTOLOGICAL AND MORPHOLOGICAL ASSESSMENT OF GONADAL MATURATION IN THE GILTHEAD SEA BREAM (*SPARUS AURATA*) FROM ALGERIAN WATERS

Mouassa Bochra

University Chadli benjdid, el Tarf, Algeria Researche lab: Epidemiological surveillance, health, production, reproduction, experimentation, and cellular therapy of domestic and wild animals

ORCID ID: https://orcid.org/ 0009-0007-3766-1274

Abstract

The gilthead sea bream is a protandrous hermaphrodite, exhibiting a unique reproductive pattern. In its first two years, it functions as a male, and upon reaching a length of over 30 cm, it undergoes a sex change, becoming female. During the male phase, the gonad is bisexual, featuring functional testicular areas with asynchronous spermatogenesis and non-functional ovarian areas. Ovarian development is also asynchronous, and females engage in batch spawning, capable of laying 20,000-80,000 eggs per day over a period of up to 3 months. Oocyte maturation coincides with a high HSI. Conversely, spawning leads to a decrease in the HSI. The size at first sexual maturity (Lm55) is 18 cm for males and 19 cm for females (The gonadosomatic index (GSI) and hepatosomatic index (HSI) in both females and males serve as indicators of a single reproduction period).

This spawning period typically extends from December to January in the Mediterranean, reproduction occurs between October and December. The eggs are spherical and pelagic, with a diameter slightly less than 1 mm and a single large oil droplet. The planktonic larval stage lasts about 50 days at temperatures of 17-18°C.

Keywords: Gilthead seabream, GSI, HSI, Hermaphrodite, Reproduction.

ASSESSMENT OF THE PRODUCTION PERFORMANCE OF INDIAN MAJOR CARP ROHU *(LABEO ROHITA)* WITH TILAPIA (*OREOCHROMIS NILOTICUS)* ON CAGE CULTURE SYSTEM IN SOUTHERN BANGLADESH

Md. Rafiqul Islam
Department of Aquaculture, Patuakhali Science and Technology University, Bangladesh

Tridip Roy
Faculty of Fisheries, Patuakhali Science and Technology University, Bangladesh

Mohammad Lokman Ali
Department of Aquaculture, Patuakhali Science and Technology University, Bangladesh

Sabrina Akter Rinju
Department of Aquaculture, Patuakhali Science and Technology University, Bangladesh

Sudipta Kumar Nag
Department of Fisheries Biology and Genetics, Patuakhali Science and Technology University, Bangladesh

Tawhidur Rahman
Bangladesh Water Development Board

Abstract

The study was conducted over 90 days in the Barguna district of Bangladesh to assess the growth and production performance of Rohu *(Labeo rohita)* in cage culture with tilapia. The experiment was designed with three treatments namely T_1 (only tilapia-100%), T_2 (tilapia-80% and rohu-20%) and T_3 (tilapia-60% and rohu-40%) respectively each having three replications. The stocking density was 50/m^3. The floating feed contained 30% protein supplied twice a day at the rate of 5-3% of their body weight. Water quality parameters were recorded every fifteen-day interval throughout the culture period. Water quality parameters were within the suitable range for fish culture. At the end of the culture period higher weight gain of Tilapia (257g) was recorded in T_3 followed by T_1(245g) and T_2(250g) and the lowest weight gain of Rohu (90.17g) was observed T_3. The survival rate of tilapia ranges from 94.2 to 96.20% and rohu from 90.15 to 90.50%. There were no significant differences ($P>0.05$) in the survival rate of tilapia and Rohu. The weight gain, % weight gain, and SGR of tilapia and rohu were found higher in T_2, followed by T_3, whereas tilapia showed higher growth in T_3 and followed by T_2 and T_1. Significantly higher ($p>0.05$) total production of fish was observed in T_1(122.46 kg), followed by T_2(111.16 kg) and T_3(98.463kg). The BCR was higher in T_1 (1.1), followed by T_2 (0.82) and T_3 (0.75). The result of the study revealed that the culture of Rohu with Tilapia in the cage is not suitable because the growth performance of Rohu was very poor. It was observed that during feeding Tilapia showed very aggressive behaviour due to the presence of their sharp spine. As a result, Rohu was not able to intake a sufficient amount of feed. So, it is not recommended to culture Indian major carp rohu with tilapia in the cages.

Keywords: Tilapia, rohu, cage culture, production

CORRELATION AND HERITABILITY OF MORPHOLOGY AND YIELD CHARACTERISTICS IN NERICA RICE GENOTYPES

Fase O.B
Department of Crop Production Technology, School of Agriculture,
ORCID ID: 0000-0002-8895-8592

Oyekale, J. I
The Federal Polytechnic, Ilaro, Ogun State, Nigeria.

ABSTRACT

Rice yield in West Africa has the potential of 3 million tons per annum, but the major constraint is water shortage, especially during periods of low rainfall, resulting in a yield loss of up to 15-20% due to drought in Africa, who depends largely on rain-fed rice production. Works need to be carried out to identify characters that can be improved on to produce rice genotypes that have the ability to thrive and be high-yielding in the upland ecology of NERICA varieties, which are usually interspecific varieties. Hence, this study evaluated the performance of 16 NERICA Varieties of rice in the Derived Savanna Ecology of Teaching and Research Farm of Olabisi Onabanjo University (OOU), Nigeria. The varieties were established in plots arranged in a Completely Randomised Design (CRD) with three replicates. Data collected on agronomic and yield characters were used to conduct character correlations and path analysis to determine the inter-relationship among the characters. Characters showed higher genotype variation and correlation relative to the phenotype values, indicating the influence of the environment. Root branching was positively correlated with seedling tiller number (0.425), seedling leaf number (0.905). It was conversely significantly correlated with seedling leaf width (-0.347). Root thickness, Final height and Spikelet number/plant had high heritability. Since most of the characters had moderate to high correlation and heritability, they are hereby recommended to breeders for further improvement of rice performance on specific adaptation programmes in upland ecology.

Keywords: Correlation, Heritability, Morphology, Yield Characteristics, NERICA Rice, Genotypes

BIOTECHOLOGICAL POTENTIAL OF ANTHOCEROTOPHYTA PYRENOIDS IN ENHANCING CROP PHOTOSYNTHESIS AND CARBON SEQUESTRATION

Vladana Brodovych

Ivan Franko National University of Lviv Ukraine

ABSTRACT

The escalating concentration of atmospheric carbon dioxide (CO2) necessitates innovative strategies for biological carbon sequestration. Conventional C3 crops, such as wheat and rice, suffer from photosynthetic inefficiency due to the oxygenase activity of the enzyme Rubisco, leading to significant energy loss through photorespiration. This paper explores the unique biophysical carbon-concentrating mechanism (CCM) found in Anthocerotophyta (hornworts), the only terrestrial plant lineage that possesses pyrenoids. Pyrenoids are sub-cellular micro-compartments within chloroplasts that aggregate Rubisco and maintain a localized environment high in CO2, thereby saturating the enzyme and suppressing photorespiration. We analyze the structural and genetic basis of pyrenoids in model species like *Anthoceros agrestis* and evaluate the feasibility of transferring these traits into vascular crops. The integration of Anthocerotophyta-derived pyrenoids into crop plants presents a promising biotechnological avenue. It has the potential to transform agriculture by significantly boosting biomass production and enhancing the natural capacity of crops to sequester atmospheric carbon. This review consolidates current findings on pyrenoid function and outlines a roadmap for developing "climate-smart" crops that contribute to global carbon reduction goals.

KEYWORDS: Pyrenoid, Anthocerotophyta ,Carbon Sequestration, Rubisco, Photosynthesis, Biotechnology.

INTRODUCTION

Increasing amount of atmospheric carbon dioxide (CO2) and the associated rise in global temperatures pose a severe challenge to terrestrial ecosystems. While CO2 is the substrate for photosynthesis, rising temperatures amplify a fundamental inefficiency in many crop plants. Major agricultural crops, including those dominating Ukraine's agricultural landscape (e.g., wheat, barley), utilize the C3 photosynthetic pathway. These plants are limited by the enzyme Rubisco, which fails to distinguish effectively between CO2 and oxygen (O2) in cases where the concentration of O2 is high. When Rubisco reacts with O2, it triggers photorespiration, which is a wasteful process that releases previously fixed carbon and consumes energy, rather than storing it.

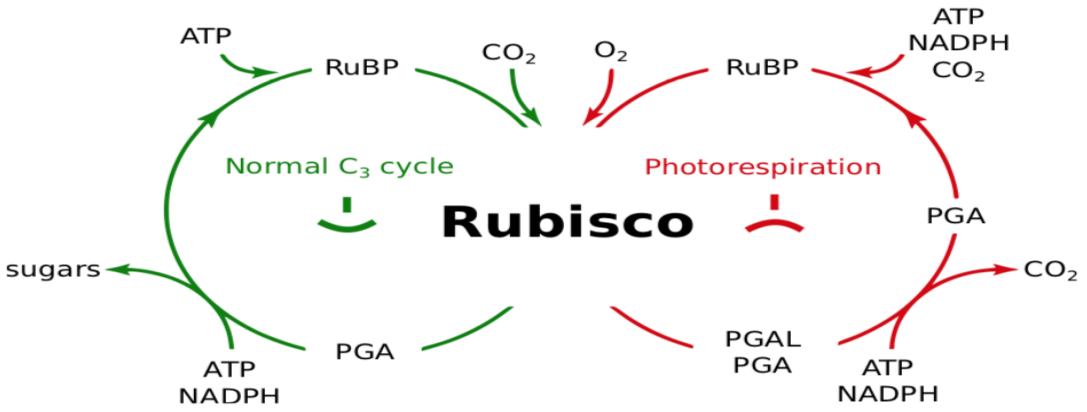


Figure 1. The dual activity of the enzyme Rubisco. Under ambient atmospheric conditions, Rubisco catalyzes both carboxylation (C3 cycle, green) and oxygenation (photorespiration, red). The latter results in carbon loss and reduces photosynthetic efficiency in C3 crops.

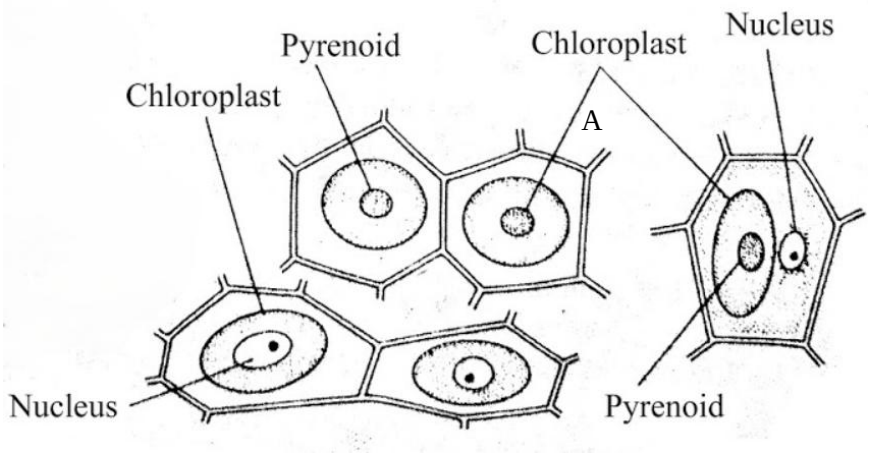
However, a unique evolutionary adaptation exists within the **Anthocerotophyta** (hornworts). Unlike other land plants, hornworts contain a specialized sub-cellular structure within their chloroplasts called the **pyrenoid** (Villarreal & Renner, 2012). This micro-compartment acts as a biophysical Carbon Concentrating Mechanism (CCM), actively accumulating CO2 to saturate Rubisco and suppress photorespiration.

This paper explores the structural and functional properties of the hornwort pyrenoid. Furthermore, we discuss the biotechnological strategy of transferring pyrenoid-based mechanisms into C3 crops. Engineering this trait offers a pathway to not only boost agricultural yields but also transform common crops into efficient agents for **biological carbon sequestration**.

RESEARCH AND FINDINGS

Localization To evaluate the potential of pyrenoid engineering, it is first necessary to understand its specific localization within the plant cell architecture. Unlike typical mesophyll cells in vascular crops, which contain numerous small chloroplasts, the cells of *Anthocerotophyta* (specifically the genus *Anthoceros*) are characterized by a unique cellular topology. They typically contain a single or few massive chloroplasts that occupy a significant portion of the cell volume (Vaughn et al., 1992).

The pyrenoid itself appears as a prominent, electron-dense body situated centrally within the chloroplast stroma. It is not an isolated granule; rather, it is functionally integrated with the photosynthetic machinery. The matrix is traversed by a network of thylakoid membranes, which act as conduits delivering inorganic carbon deep into the Rubisco aggregate (Vaughn et al., 1992).



SCHEME 1. Schematic representation of the *Anthoceros* cell (A) Two cells showing chloroplast with pyrenoid in the centre; (B) A single cell showing chloroplast with pyrenoid (C) Parenchyma cells with chloroplast and pyrenoid. [6]

Mechanism of biological CCM The operational efficiency of the hornwort pyrenoid relies on a three-step biophysical mechanism, described by Meyer & Griffiths (2013), that distinguishes it from the passive diffusion found in C3 crops. Firstly, the plant actively transports inorganic carbon (C_i) across the chloroplast envelope, primarily in the form of bicarbonate (HCO_3^-), creating a high internal pool of carbon. Secondly, bicarbonate diffuses into the pyrenoid matrix through the thylakoid tubules. Last but not least, the enzyme *Carbonic Anhydrase (CA***)**, localized specifically within the pyrenoid tubules, catalyzes the rapid dehydration of bicarbonate back into molecular CO_2. This creates a localized "CO_2-cloud" around the Rubisco active sites, effectively saturating the enzyme and inhibiting oxygenation (Meyer & Griffiths, 2013).

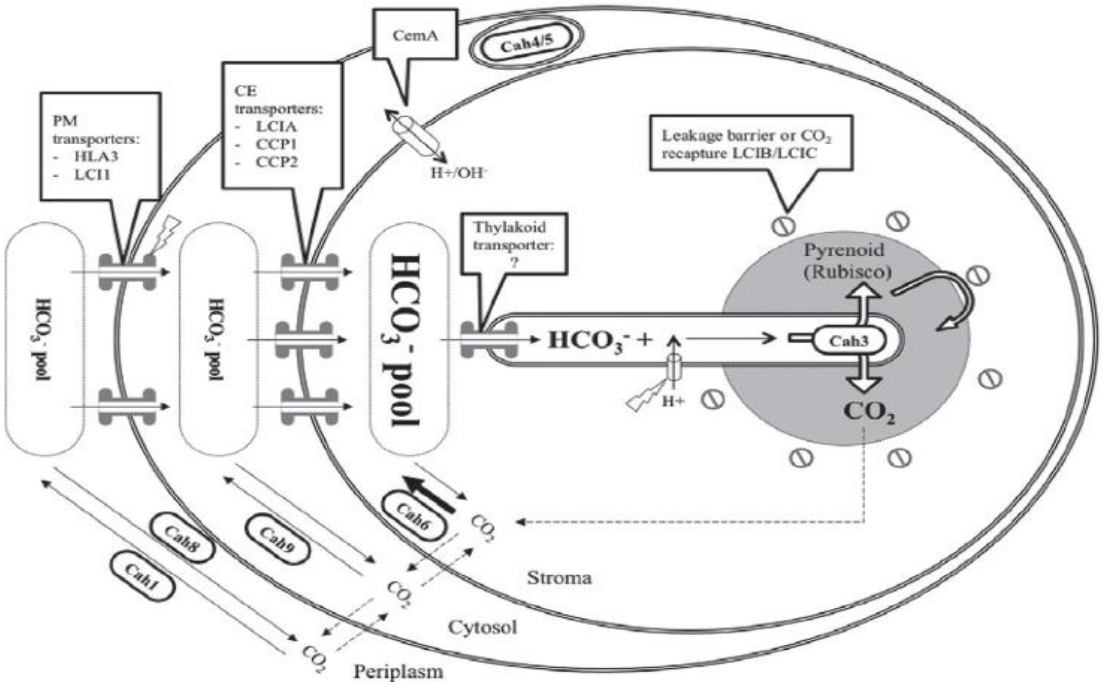


Figure 2. Hypothetical model of the C. reinhardtii biophysical CCM (Carbon Concentrating Mechanism). While based on the algal model *Chlamydomonas reinhardtii*, the fundamental components illustrated here—bicarbonate transporters, the thylakoid sheath, and

pyrenoid-localized Carbonic Anhydrase (Cah3)—are functionally analogous to the mechanism found in *Anthocerotophyta*. [2]

The physiological advantage of this mechanism is evident when comparing the photosynthetic response to varying CO_2 levels (A/C_i) between standard C3 crops and pyrenoid-containing species. C3 crops like wheat show a linear dependency on external CO_2 and suffer from photorespiration under ambient conditions. In contrast, hornworts demonstrate kinetics similar to C4 plants, maintaining high photosynthetic rates even at low carbon concentrations due to the lower CO_2 compensation point.

Anthocerotophyta undoubtedly possess the desired traits for efficient carbon-sequestration. However, their direct mass cultivation near large industrial conglomerations is impractical due to their sensitivity to air pollution. Therefore, the strategic approach involves isolating the genetic machinery that is responsible for pyrenoid formation and transferring it into resilient high-biomass crops.

Recent genomic sequencing of *Anthoceros agrestis* has revealed that the pyrenoid is a multigenic trait. Key targets for engineering include, genes encoding modified RBCS proteins responsible for aggregation, genes encoding proteins that act as a molecular "glue" and genes that encode specific isoforms localized to the pyrenoid.

By isolating these gene clusters using PCR amplification and introducing them into the genome of staple Ukrainian crops—such as wheat (*Triticum aestivum*) and maize (*Zea mays*)—via **Agrobacterium-mediated transformation**, it is theoretically possible to induce pyrenoid formation in crop chloroplasts (Hennacy & Jonikas, 2020).

Implementing a pyrenoid-based CCM is expected to have profound physiological effects beyond simple carbon fixation.First of all , it is vital to consider an increased amount of biomass and the resulted water efficiency**.** Primarily, the suppression of photorespiration means the plant stops wasting energy on recycling oxygen. This conserved energy is predicted to be channeled into vigorous vegetative growth and **root development**, significantly boosting total biomass. Furthermore, the high internal CO_2 concentration created by the pyrenoid allows plants to maintain narrower stomatal apertures. This reduces transpiration rates, thereby enhancing **Water Use Efficiency (WUE)**. This trait is particularly valuable for adapting agriculture to increasingly arid climatic conditions and ensuring survival during heatwaves.

The anticipated increase in carbohydrate synthesis offers a significant boost to caloric yield. However, this accumulation of starch necessitates a careful examination of the Carbon-to-Nitrogen (C:N) ratio within the grain. A potential "dilution effect" could occur if nitrogen uptake does not scale proportionally with carbon fixation, theoretically impacting protein content (Taub & Wang, 2008). Consequently, deploying this technology will likely require optimized soil management or co-engineering of nitrogen assimilation pathways to ensure that the crops remain both high-yielding and nutrient-dense.

CONCLUSION

The integration of the Anthocerotophyta-derived biophysical Carbon Concentrating Mechanism into C3 crops represents a transformative frontier in plant biotechnology. Our review highlights that the hornwort pyrenoid is a sophisticated, modular organelle capable of overcoming the inherent limitations of the enzyme Rubisco. By identifying and transferring the key genetic components—specifically the modified Rubisco Small Subunit, linker proteins, and pyrenoid-localized Carbonic Anhydrase—it is theoretically feasible to engineer a functional CCM in staple crops like wheat and maize . Such "climate-smart" crops would offer a dual

solution to the global crisis: ensuring food security through increased yields and drought tolerance, while simultaneously turning agricultural lands into active sinks for biological carbon sequestration.

REFERENCES

1. Hennacy, C. M., & Jonikas, M. C. (2020). Prospects for engineering biophysical CO2 concentrating mechanisms into land plants to enhance yields. Annual Review of Plant Biology, 71, 461–485. https://www.annualreviews.org/content/journals/10.1146/annurev-arplant-081519-040100

2. Meyer, M., & Griffiths, H. (2013). Origins and diversity of eukaryotic CO2-concentrating mechanisms: lessons for the future. Journal of Experimental Botany, 64(3), 769–786. https://academic.oup.com/jxb/article/64/3/769/533257

3. Taub, D. R., & Wang, X. (2008). Why are nitrogen concentrations in plant tissues lower under elevated CO2? A critical examination of the hypotheses. https://onlinelibrary.wiley.com/doi/10.1111/j.1744-7909.2008.00754.x

4. Vaughn, K. C., Ligrone, R., Owen, H. A., Hasegawa, J., ... & Renzaglia, K. S. (1992). The anthocerote chloroplast: a review. New Phytologist. https://nph.onlinelibrary.wiley.com/doi/10.1111/j.1469-8137.1992.tb05653.x

5. Villarreal, J. C., & Renner, S. S. (2012). Hornwort pyrenoids, carbon-concentrating structures, evolved and were lost at least five times during the last 100 million years. Proceedings of the National Academy of Sciences, 109(46), 18873–18878.

6. https://premabotany.blogspot.com/2018/12/anthoceros.html

ASSESSMENT OF THE EFFECTS OF STABILIZED MUNICIPAL ORGANIC WASTE COMPOSTS ON TOMATO (*SOLANUM LYCOPERSICUM* L.) GROWTH AND ENZYMATIC ACTIVITIES OF PEROXIDASE AND SUCCINATE DEHYDROGENASE

Ilham Chennak

Laboratory of Water and Environment, Department of Chemistry, Faculty of Sciences, Chouaïb Doukkali University, 24 000, El Jadida, Morocco.

Lamiaa Belasri

Laboratory of Health and Environment, Department of Biology, Faculty of Sciences Ain Chock, Hassan II, 20 470 Casablanca, Morocco.

Mohammed El Krati

Laboratory of Water and Environment, Department of Chemistry, Faculty of Sciences, Chouaïb Doukkali University, 24 000, El Jadida, Morocco.

Samah Ait Benichou

Laboratory of Health and Environment, Department of Biology, Faculty of Sciences Ain Chock, Hassan II, 20 470 Casablanca, Morocco.

ABSTRACT

This study examined the effects of four mature municipal solid waste composts on the cultivation of *Solanum lycopersicum* L. It assessed the impact of different application rates (0, 5, 10, and 20 t/ha) on plant growth, as well as on the leaf activities of peroxidase (Prx) and succinate dehydrogenase (SDH). Overall, compost application, regardless of the dose, significantly enhanced all measured parameters. Stem height, root length, fresh biomass, leaf number, and leaf area increased markedly and proportionally with rising compost doses. The highest increases in chlorophyll content and total soluble sugars were recorded with the higher application rates of composts.

Keywords: MSW compost; Solanum lycopersicum; enzymatic activities.

ASSESSING THE HETEROGENEOUS EFFECTS OF RAINFALL AND IRRIGATION ON AGRICULTURAL PRODUCTIVITY IN BANGLADESH: TAKEAWAYS FOR CLIMATE SMART AGRICULTURE

MD. Kabir Hossain

Lecturer, Rajendrapur Cantonment Public School and College at Rajendrapur, Gazipur, Bangladesh

Abstract

The agricultural production system in Bangladesh is predominantly rain-fed. The rain-fed agriculture system is vulnerable to climate change impact. The impact of climate change occurs at multiple scales (global, regional and national) and sectors (including agriculture). The agricultural sector and its sub-sectors are increasingly showing a high level of vulnerability and impact. The impact of climate change and variability on agricultural production would engender appropriate policies and practices towards a sustainable agricultural production system.

This study try to find out that the various impacts of rainfall and irrigation on agricultural production in Bangladesh and drew key takeaways for climate-smart agriculture (CSA) in Bangladesh. We use 44 years' time series data that are extracted from national and international sources. Descriptive and inferential analyses (averages, standard deviations and correlations) were used to analyze the dataset to elucidate the variables. The estimation followed an autoregressive integrated moving average (ARIMA) model style. The GMM technique was used to estimate the parameters of the model that was used for estimating the impact of rainfall and irrigation on aggregate agricultural production and by sub sectors (all crops, staples, livestock, fisheries and forestry). Irrigation had positive and significant impact on aggregate agricultural production as well as all sub-sectors of agriculture. These findings suggest the need for the minimization of the impact of climate-induced production risks through CSA which would involve complementary development of more arable land areas under irrigation in Bangladesh. Irrigation would also enhance complementary agricultural water management for the development of all the sub-sectors of agriculture. So under climate change and variability irrigation help agricultural production and helps to obtain food security and sustainable development. Finally these studies provide appropriate and necessary policies that helps to enhancing food security and sustainable agricultural production under prevailing climate change and variability.

Keywords: Rainfall, Irrigation, Heterogeneous Effects, Agricultural Productivity, Climate Smart Agriculture (CSA).

INDIGENOUS ALDER (*ALNUS NEPALENSIS*) BASED AGROFORESTRY SYSTEMS AMONG TRIBAL COMMUNITIES OF NAGALAND: A PATHWAY TO SUSTAINABLE LAND USE

Jayashree Chowdhury

Assistant Professor, Department of Economics, Handique Girls' College, Guwahati, India

Bandana Chowdhury

Assistant Professor, Department of Economics, Gauhati University, Guwahati, India

Sourav Deuri

Guest Lecturer, Department of Economics, Handique Girls' College, Guwahati, India

Abstract

The rich and diversified valley of Northeast where Nagaland's hilly landscape is facing persistent ecological challenges since immortal including unstable slopes, heavy rainfall, shallow soils and the long-term impacts of shortened jhum shifting cultivation cycles. As a result of which fallows are shrinking, soil fertility declines, erosion intensifies and livelihoods become vulnerable in this region. Amid all these ongoing pressures, several tribal communities of Nagaland such as the Angami, Chakhesang, Chang, Yimchunger and Konyak have developed an indigenous agroforestry practice centred on *Alnus nepalensis* (Himalayan alder). In this process, alder trees are retained and periodically pollarded within jhum fields while a variety of food, tuber and cash crops are cultivated beneath them. The tree's nitrogen-fixing ability continuous litterfall and strong root system enhances the soil fertility, thus improving slope stability and allowing sustained cropping even on steep terrain.This paper reviews the biological characteristics of *Alnus.nepalensis*, portraying the cultural origins and management of the alder-based system and assessing its ecological and socio-economic impacts. The paper also shows the clear benefits in terms of soil enrichment, erosion control, diversified production and livelihood support. In this context, the various ongoing challenges such as labour demands, market limitations, biodiversity trade-offs and issues of tenure are also highlighted throughout the study. Overall, the alder-based system is presented as a valuable indigenous model for sustainable land use in mountainous regions and a potential framework for scaling in similar landscapes.

Keywords:*Alnus nepalensis*, agroforestry, jhum, Nagaland, indigenous land-use, nitrogen fixation, slope stabilization, sustainable farming.

STUDYING THE EFFECT OF HEMATITE AND TITANIUM DIOXIDE NANOPARTICLES ON REDUCING CADMIUM LEVELS IN WHEAT GRAIN: A REVIEW

Fateme Asadi Touranlou

Department of Nutrition, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran

Abstract

Introduction: Cadmium (Cd) accumulation in wheat grain poses a significant risk to food safety and human health due to its high toxicity and bioavailability. With increasing soil contamination from industrial and agricultural sources, conventional remediation strategies often prove inefficient or costly. Recent studies have explored engineered nanoparticles, particularly hematite (Fe_2O_3) and titanium dioxide (TiO_2), as promising immobilizing agents that reduce Cd uptake and translocation in crops.

Methods: This review synthesizes findings from 28 peer-reviewed studies (2015–2025) identified through Scopus, Web of Science, and PubMed using keywords such as "hematite nanoparticles," "titanium dioxide nanoparticles," "cadmium immobilization," and "wheat grain." Inclusion criteria comprised pot and field experiments evaluating Cd concentration in wheat tissues following nanoparticle amendment (doses 10–500 mg kg^{-1} soil), with or without Cd-spiked conditions. Data on soil Cd bioavailability, plant uptake, translocation factors, grain Cd content, oxidative stress markers, and yield parameters were systematically compared.

Results: Both hematite and TiO_2 nanoparticles significantly reduced bioavailable Cd in soil (25–78%) through adsorption, complexation, and pH-dependent surface reactions. Foliar or soil-applied nanoparticles decreased Cd concentration in wheat grain by 32–89%, with hematite generally outperforming TiO_2 at equivalent doses. Mechanisms included enhanced Cd fixation in roots, reduced translocation to shoots, and alleviation of Cd-induced oxidative stress. No consistent phytotoxicity or yield penalty was observed at optimal doses (≤100 mg kg^{-1}).

Conclusion: Hematite and TiO_2 nanoparticles offer an effective, eco-friendly approach for mitigating Cd accumulation in wheat grain. Hematite shows particular promise due to superior adsorption capacity and lower cost. Further field-scale and long-term studies are needed to confirm efficacy, safety, and regulatory feasibility before widespread agricultural adoption.

ISOLATION OF SAHARAN ACTINOBACTERIA FOR BIOLOGICAL CONTROL AGAINST PHYTOPATHOGENS: TOWARDS SUSTAINABLE AGRICULTURE

Fedwa BEGHDADI

Laboratory of Molecular Biology, Genomics and Bioinformatics (LBMGB), Faculty of Natural Sciences and

El-Hadj DRICHE

Life (SNV), Hassiba Benbouali University of Chlef, Hay Salem, 02000 Chlef, Algeria.

Abstract

Throughout their lives, plants interact with various organisms, which can negatively or positively impact their health, leading to significant agricultural losses. Biological control, particularly through the use of antagonistic actinomycetes, represents a promising method to combat these phytopathogens. Therefore, this study aims to screen new strains of actinomycetes isolated from Saharan soil, which produce bioactive molecules that inhibit some phytopathogenic agents.

For the isolation of Saharan actinomycetes, several soil samples were collected from various oases in Algeria. These samples were treated using the CaCO3 method and subjected to a series of decimal dilutions, and subsequently inoculated onto the CHV medium with or without selective agents, with incubation carried out at 30°C for 21 days. The antimicrobial activity of actinomycetes against these pathogens was assessed using the cross streaking method on ISP2 and YGB mediums. Incubation was done at 30°C for 24 hours for bacteria and up to 3 days for fungi (Aouiche et al 2013).

This method of isolation among us has resulted in obtaining a significant number of actinomycete isolates with the potential to inhibit phytopathogenic bacteria and fungi, with the inhibition diameter reaching up to 40mm for some strains on the solid YGB medium.

The intensity of the variable activity largely depends on the type or group to which the strains belong. These variations in the number of activities are due to the fact that a strain of actinobacteria can produce several antimicrobial molecules with different modes of action depending on the composition of the culture medium (Berdy, 2005 and 2012).

In view of the results obtained, we can consider that our actinomycete isolates have the ability to inhibit certain phytopathogenic agents. The production, extraction, and characterization of these bioactive molecules is the subject of our current research.

Keywords: Actinomycetes, Bioactive molecules, Phytopathogenic agents, Biological control.

ENVIRONMENTAL AND CONSUMER HEALTH RISKS ASSOCIATED WITH MYCOTOXINS PRODUCED BY PHYTOPATHOGENIC FUNGI

Fedwa BEGHDADI

Laboratory of Molecular Biology, Genomics and Bioinformatics (LBMGB), Faculty of Natural Sciences and

El-Hadj DRICHE

Life (SNV), Hassiba Benbouali University of Chlef, Hay Salem, 02000 Chlef, Algeria.

Abstract

Pathogenic fungi inflict great damage on plants, leading to their wilting, damage, or death in many cases, by secreting hydrolases that dissolve the cells of the plant tissue on which they feed. Among these plant-pathogenic fungi we find: *Botrytis ceneria, Fusarium oxysporum, Alternaria, Phytophthora infestans* ... these have a negative impact on health, food safety and lead to significant losses.

Under certain climatic or storage conditions, these microorganisms can develop and lead to the production of mycotoxins, which can be harmful to the health of animals and humans, causing a number of disorders and even serious illnesses. These toxic metabolites therefore represent a major health problem.

Around 25% of food products are contaminated with fungal toxins. The mycoflora is estimated to comprise between 200,000 and 300,000 species. There is therefore a wide diversity of mycotoxins. Of the more than 400 mycotoxins identified, only 30 or so have worrying toxic properties. Some of these toxins are thought to be carcinogenic or mutagenic, while others are toxic to the kidneys, nervous system or liver. It should also be noted that toxicity does not necessarily stem from the mycotoxin itself, but may be due to one of the metabolites produced by its degradation.

Several species of micromycetes, mainly belonging to the four genera *Aspergillus, Penicillium, Fusarium and Alternaria,* are capable of excreting one or more mycotoxins: aflatoxins, ochratoxins, fumonisins, trichothecenes, patulin, zearalenone, alternariols…

The lack of sanitary controls, poor food packaging (damp, hot, poorly ventilated storage areas) and the absence of strict regulations increase the risk of contamination by these metabolites. The frequency of contamination of foodstuffs available to the public and their mycotoxin content are becoming a serious threat to health.

Keywords: Mycotoxins**;** Phytopathogenic fungi**;** Food contamination**;** Toxicity**;** Food safety

DEVELOPMENT OF NANO-BASED LIQUID BIOFERTILIZER FOR MITIGATION OF SALT STRESS IN CAPSICUM ANNUUM L AND SOLANUM MELONGENA PLANTS

Shyamnath. S

School of Bioengineering, Bharath Institute of Higher Education and Research, Selaiyur, Chennai, Tamil Nadu 600073, India.

Sandhia.S

School of Bioengineering, Bharath Institute of Higher Education and Research, Selaiyur, Chennai, Tamil Nadu 600073, India.

Jeyanthi Rebecca.L

School of Bioengineering, Bharath Institute of Higher Education and Research, Selaiyur, Chennai, Tamil Nadu 600073, India.

Abstract

Salinity is one of the most important environmental stress which threatens the global crop production, and also soil salination is increasing due to the increasing sea level, and also it is going to increase more in the future, hence a sustainable solution is required to mitigate the adverse effects of salt stress in plants. This study aimed to produce a liquid biofertilizer containing *Halomonas aquamarina* incorporating silica, copper oxide, and iron nanoparticles to mitigate the adverse effects of salt stress in plants. This experiment was conducted in a controlled environment under a hydroponics setup for two weeks, using one-month-old *Capsicum annuum L* and *Solanum melongena.* Seedlings. After one week of NaCl treatment, the plants were treated with the nano-based liquid biofertilizer, and morphological, physiological, and biochemical analyses were conducted. The results showed that the biofertilizer with the incorporation of nanoparticles mmproved the ascorbate peroxidase activity by 33 to 60 percent in salt-stressed plants, and improves photosynthetic pigments under stress conditions and also found that the *Halomonas aquamarina* have found to enhance the root growth. The study concluded that the biofertilizer made with *H. Aquamarina* along with silica, copper oxide, and iron oxide nanoparticles incorporated in it had mitigated the adverse effects of salt stress in plants.

Keywords: *Halomonas Aquamarina*; silica; copper oxide; iron; Ascorbate peroxidase, Biofertilizer, salt stress; Capsicum annuum L, *Solanum melongena.*

GREEN SYNTHESIS OF *MELIA DUBIA* MEDIATED SILVER NANOPARTICLES AND EXPLORING IT'S ANTIBACTERIAL PROPERTY IN MASTITIS PATHOGENS

Lazima.G, Ranjani S

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

S. Hemalatha

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

Abstract.

Antibiotic resistance among bovine mastitis pathogens presents a critical challenge to animal health, milk quality, and the global dairy industry. Conventional therapies becoming increasingly ineffective, the development of sustainable antimicrobial alternatives is essential. Silver nanoparticles (AgNPs) were synthesized using the leaf extract of *Melia dubia*, providing a green, eco-friendly, and cost-effective approach to nanoparticles synthesis. The phytochemicals in the extract acted as natural reducing and stabilizing agents. The synthesized AgNPs were characterized using UV–Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Zeta Potential analysis, and Field Emission Scanning Electron Microscopy (FESEM). These techniques confirmed the synthesis of nanoparticles, crystalline structure, colloidal stability, and the presence of functional groups responsible for capping and stabilization. The antibacterial activity of the green-synthesized AgNPs was evaluated in major multidrug-resistant mastitis pathogens, including *Klebsiella pneumoniae, Escherichia coli, and Acinetobacter baumannii*. The AgNPs exhibited strong inhibitory effects, reflected by reduced bacterial growth, membrane disruption, and interference with vital cellular functions. Their antimicrobial mechanism is attributed to generation of oxidative stress, enhanced membrane permeability, and interaction with intracellular biomolecules. This study demonstrates the promising potential of *Melia dubia*-mediated AgNPs as an effective alternative antimicrobial strategy for managing bovine mastitis. The integration of biogenic nanoparticles may help reduce antibiotic dependency, mitigate resistance development, and support sustainable livestock healthcare.

Keywords: Silver nanoparticles; Green synthesis; *Melia dubia*; Bovine mastitis; Antimicrobial activity; Multidrug-resistant pathogens

PHYTO-SYNTHESIS OF NANOPARTICLES TO CONTROL MULTIDRUG RESISTANCE GRAM NEGATIVE PATHOGENS

Abinaya V

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

Ranjani S

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

S. Hemalatha

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

Abstract

Antibiotic resistance has created significant impact on global healthcare system. *Ormocarpum cochinchinense* is a medicinal plant belonging to the family Fabaceae which is widely distributed in tropical regions Southeast Asia. *Ormocarpum cochinchinense* is rich in flavonoids and phenolic compounds, was utilized for the phyto-synthesis of silver nanoparticles (Oc-AgNPs). The plant extract acted as both reducing and stabilizing agent, promoted an eco-friendly synthesis route. The synthesized Oc-AgNPs were characterized using XRD, EDAX, FESEM and DLS analyses, confirming the formation of crystalline, spherical nanoparticles ranging from 20 to 50 nm with high elemental purity and stability. The antimicrobial efficacy of Oc-AgNPs was evaluated in *Escherichia coli* and *Klebsiella pneumoniae*. MIC and MBC assays demonstrated potent antibacterial activity at low concentrations, while biofilm inhibition assays revealed significant disruption of bacterial adherence. The results indicate that Oc-AgNPs effectively suppress Gram-negative pathogens and could serve as promising alternatives to conventional antibiotics. Biochemical assessment confirmed that the treatment with Oc-AgNPs caused bacterial membrane leakage and oxidative stress, indicated by increased lipid peroxidation and decreased CAT, SOD activity. Furthermore, the incorporation of Oc-AgNPs into hydrogel matrices enhances their stability and enables controlled release, making them suitable for wound healing and biomedical applications.

Keywords: *Ormocarpum cochinchinense*, Nano therapeutics, Nanoparticles, Antimicrobial activity, Anticancer activity, Hydrogel

NANO-ENGINEERED ANTIMICROBIAL FORMULATION FOR THE CONTROL OF PLANT PATHOGEN

Kovendan M

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

S. Hemalatha

School of Life Sciences, B.S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, India.

Abstract

Pathogenic attack and extension of shelf life of agricultural produce are global challenges in crop protection and post-harvest management. Pathogenic attacks significantly affect crop health which leads to dwarfing, leaf abscission and yield loss. Conventional preservation and plant protection techniques often rely on chemical treatments which raises environmental and health risks. This study addresses this issue and focus on developing a sustainable Nano-engineered treatment aiming for inhibiting these pathogenic microorganisms and to enhance the quality of crops. The core innovation is to synthesize a silver nanoparticles using young neem leaves (*Azadirachta indica*) which is well-known for its antimicrobial properties and the bioactive phytochemicals present acts as safe and eco-friendly reducing agents of AgNPs. Encapsulation of AgNPs into nanoemulsion enhance its stability, bioavailability, dispersion and antibacterial activity. The synthesized green nanoparticals (AIAgNPs) and nanoemulsion (AIAgNE) were characterized using UV-Vis spectroscopy, Dynamic Light Scattering (DLS), zeta potential, Fourier Transform Infrared Spectroscopy (FTIR), and X-ray Diffraction (XRD) analysis. Antibacterial efficacy of synthesized AIAgNPs and AIAgNE against two pathogenic strains of pseudomonas aeruginosa (SES4 & SES5) which has been isolated from infected sesame leaves were evaluated by MIC, MBC and Anti-biofilm formation assay. The antibacterial activity of synthesized AIAgNPs and AIAgNE with *Pseudomonas Aeruginosa* were tested at different time intervals, AIAgNPs reduced bacterial growth to 28% (SES4) and 15% (SES5), while AIAgNE showed strong inhibition with 10% (SES4) and 12% (SES5). Thus AIAgNE demonstrated the most effective antibacterial anti-biofilm activity compared to AIAgNPs. The study proves that the synthesized green silver nanoparticles using *Azadirachta indica* is effective in controlling the plant pathogens.

Keywords: Green synthesis, *Pseudomonas Aeruginosa*, *Azadirachta indica*, Preservation

AGRICULTURAL BIODIVERSITY AND FOOD SECURITY: A COMPARISON WITH EXAMPLES FROM TURKEY AND THE WORLD

Emine Kokaçya DUVAN

Dr. Independent Researcher; Kadirli/Osmaniye, Türkiye

ORCID ID: https://orcid.org/0000-0002-9180-9651

Semin TOPALOĞLU PAKSOY

Assoc. Prof. Dr., Çukurova University, Faculty of Economics and Administrative Sciences, Department of Econometrics, Adana, Türkiye

ORCID ID: https://orcid.org/0000-0003-1693-0184

Abstract

Introduction and Purpose: Agricultural biodiversity is a fundamental component of sustainable food systems and is strategically important for food security in the face of climate change, population growth, and global market volatility. Declining biodiversity makes food security vulnerable in the short and long term, while also threatening the sustainability of agricultural production. This study evaluates Türkiye's agricultural biodiversity structure from a food security perspective and compares it with global examples, aiming to present a holistic approach to conservation, sustainable use, and policy development.

Materials and Methods: A mixed-methods approach was adopted in the study; Türkiye's agricultural biodiversity capacity was assessed using quantitative indices and qualitative policy analyses. Quantitative analyses were conducted using crop diversity, genetic resource density, and food security indicators. Qualitative analyses were conducted using policy documents, seed legislation, and international reports. Türkiye's agricultural biodiversity potential was compared with selected countries from America, Europe, Africa and Asia.

Conclusions: The findings indicate that agricultural biodiversity strengthens its critical role in food security, particularly through production diversification, the protection of local species, the development of farmer information systems, and the dissemination of digital agriculture practices. Comparison with global examples (such as India, Mexico, and Italy) reveals that local seed policies implemented in countries with high biodiversity centers strengthen the stability dimension of food security.

Discussion and Conclusion: Protecting biodiversity and local seeds is not only an environmental imperative but also a strategic priority for Türkiye's and the world's food security policies. While Türkiye is a country rich in genetic diversity, it faces the risk of genetic erosion due to monoculture pressure and reliance on hybrid seeds. Global examples demonstrate that food supply vulnerability is lower in countries with strong local seed policies. A policy-driven holistic management approach will enable Türkiye to maximize the potential of agricultural biodiversity and build a sustainable food system aligned with global trends.

Key Words: Agricultural biodiversity; Food security; Genetic resources; Diversity indices; Comparative analysis; Türkiye

CHARACTERIZATION OF LEAVES, ROOTS, AND SOIL OF MEDICINAL AROMATIC PLANTS: SOIL-PLANT TRANSFER

Ikram Elbezyouy
1Ecological engineering team, Laboratoire de Génie Environnemental, Ecologique, Agro-Industriel, Faculté des Sciences et Techniques, Université Sultan Moulay Slimane, BP 523, 23000 Béni Mellal, Morocco.

Ilias Oussif
1Ecological engineering team, Laboratoire de Génie Environnemental, Ecologique, Agro-Industriel, Faculté des Sciences et Techniques, Université Sultan Moulay Slimane, BP 523, 23000 Béni Mellal, Morocco.

Aabdousse Jamal
1Ecological engineering team, Laboratoire de Génie Environnemental, Ecologique, Agro-Industriel, Faculté des Sciences et Techniques, Université Sultan Moulay Slimane, BP 523, 23000 Béni Mellal, Morocco.

Wahid Nadya
1Ecological engineering team, Laboratoire de Génie Environnemental, Ecologique, Agro-Industriel, Faculté des Sciences et Techniques, Université Sultan Moulay Slimane, BP 523, 23000 Béni Mellal, Morocco.

Abstract

The use of aromatic medicinal plants has long highlighted their importance for human health, the food industry, and nutrition. However, our study will focus on an aromatic medicinal plant widely recognized for its therapeutic properties and use in traditional medicine. This species belongs to the Ericaceae family, typical of areas with a Mediterranean climate. Despite its great socio-economic and ecological importance, adaptation to environmental stress, and regeneration, it remains undervalued. However, its exposure to radioactive elements present in the environment via soil-plant transfer can have nutritional consequences. This work aims to determine the rate of transfer of radioactive elements from the soil to the roots and leaves at three geographically different sites in the Beni Mellal region, based on the quantitative use of LR 115 detectors for measuring uranium and thorium.

The principle of solid nuclear trace detectors is based on interaction with the environment (soil, crushed leaves, crushed roots). This DSTN technique, based on autoradiographic contact with samples, depends on knowledge of the stopping power of particles in the samples studied and the recording sensitivity of the detector.

Keywords: Soil-plant transfer, LR115, Solid detectors, Medicinal aromatic plants, Impact of radioactivity.

HERBAL COSMETICS: TRENDS, SAFETY & EFFICACY

S.Rubin Thara

N.Arshad Ahamed

E.Praveena

R.Swathi

R.Sriarasuvasan

K.Dinesh Rajan

D.Aravindhan

K.Vaishnavi

K.Vijalakshmi

Faculty of pharmacy, Bharath institute of higher education and research, chennai, India

Abstract

Herbal cosmetics have gained significant global acceptance due to increasing consumer awareness of natural ingredients, safer formulations, and holistic beauty care. These products incorporate plant-derived components such as essential oils, extracts, and phytochemicals that offer functional benefits including moisturization, anti-aging effects, UV protection, and acne management. Current trends highlight a shift toward green formulations, sustainability, clean beauty, and the integration of advanced technologies like nano-herbal delivery systems to enhance skin penetration and stability. Despite their growing popularity, safety concerns remain, particularly regarding adulteration, contamination with heavy metals, unstandardized extracts, and undisclosed synthetic additives. Regulatory challenges also persist, as many herbal cosmetic products lack rigorous standardization and quality control compared to conventional cosmetics. Nevertheless, scientific evidence increasingly supports the efficacy of various herbal ingredients, such as aloe vera, turmeric, neem, and green tea, which demonstrate antioxidant, antimicrobial, and anti-inflammatory activities. This article reviews recent trends in the herbal cosmetic industry, evaluates the safety aspects associated with their use, and highlights evidence-based data regarding their efficacy. Overall, herbal cosmetics present promising alternatives to synthetic products, provided that proper standardization, safety assessment, and regulatory compliance are ensured.

Keywords: Herbal cosmetics, phytochemicals, safety, efficacy, natural ingredients, clean beauty, standardization, skin care, plant extracts, nano-herbal formulations.

FOAM-MAT DRYING: A SUSTAINABLE TECHNOLOGY TO REDUCE POST-HARVEST LOSSES AND ADD VALUE TO AGRI-FOOD PRODUCTS

Mostafa OUHSSAINE

Karim OUSSAID

Sanaa CHERROUD

Ayoub AINANE

Tarik AINANE

Khénifra Higher School of Technology, Sultan My Slimane University, BP170, Khenifra, Morocco

ABSTRACT

Foam-Mat Drying is an emerging drying process that is gaining interest in the agri- food and environmental sectors due to its efficiency, low energy cost, and ability to preserve the qualitative characteristics of processed products. It involves incorporating foaming and stabilizing agents into a liquid or food puree to form a stable foam, which is then spread in a thin layer and dried in hot air. This modification of the product's structure significantly increases the exchange surface area and reduces internal diffusion resistance, allowing for faster drying at moderate temperatures while minimizing the degradation of bioactive compounds, natural pigments, and volatile aromas.

In many countries, particularly those with hot climates, post-harvest losses are a major challenge, sometimes affecting more than 30% of annual production. Fruits, vegetables, and perishable products with high water content are particularly susceptible to physical, microbiological, and biochemical deterioration. Foam-Mat Drying offers a sustainable technological response to these constraints, enabling the rapid transformation of unstable raw materials into stable powders that are easy to transport, store, and incorporate into food formulations. This process thus promotes local added value, waste reduction, and extended shelf life.

In addition, the flexibility of the process—applicable to various products such as juices, purées, plant extracts, dairy products, and spices—makes it a technology suitable for small and medium-sized agri-food units. By limiting the need for complex equipment and energy, it is fully in line with a sustainability approach and the transition to more responsible processes. Foam-Mat Drying is therefore a promising solution for improving food safety, supporting bio-valorization, and addressing environmental issues related to post-harvest losses.

Keywords: Foam-Mat Drying - Post-harvest losses - Agri-food recovery - Sustainability

INTEGRATED VALORIZATION OF QUINOA PROCESSING BY-PRODUCTS: FROM FUNCTIONAL FOOD INGREDIENTS TO BIOENERGY AND AGRICULTURAL APPLICATIONS

BENYAHOUB Rabie

Laboratory for the Protection of Ecosystems in Arid and Semi-Arid Zones, Kasdi Merbah University –Algeria-

CHOUANA Toufik

Laboratory for the Protection of Ecosystems in Arid and Semi-Arid Zones, Kasdi Merbah University –Algeria-

AZIB Salim

Bioresources Laboratory, Kasdi Merbah University–Algeria-

Abstract

Introduction: Quinoa (*Chenopodium quinoa* Willd.) processing generates substantial amounts of by-products, including husks, bran, and saponin-rich residues. These materials are often discarded despite their richness in bioactive compounds and nutrients. In the context of a circular bioeconomy, such by-products represent promising resources for sustainable valorization. This project aims to develop an integrated approach for converting quinoa processing wastes into value-added products across the food, bioenergy, and agricultural sectors.

Materials and Methods: The planned work focuses on three complementary valorization pathways:
(1) Extraction of functional food ingredients from quinoa bran (dietary fibers, proteins, antioxidant compounds);

(2) Bioenergy production through anaerobic digestion or fermentation of quinoa residues to generate biogas or bioethanol;

(3) **Agricultural applications**, assessing composted biomass and residual material as soil amendments to enhance soil fertility.

These methodological approaches are currently under development as part of the project's initial phase.

(Expected) Results: As this research is in its early stages, experimental results are not yet available. However, based on existing literature, these pathways are expected to yield functional ingredients suitable for incorporation into health-promoting foods, renewable energy derived from quinoa residues, and nutrient-rich amendments capable of improving soil quality.

Discussion / Conclusion: The integrated valorization approach proposed in this project has strong potential to reduce environmental impacts and generate new economic opportunities within the quinoa production chain. Although results are forthcoming, the conceptual framework supports the development of sustainable agrifood systems in emerging regions. This

work highlights quinoa’s value beyond its grains, promoting holistic use of its processing by-products for food, energy, and agricultural sustainability.

Keywords: Quinoa by-products; functional ingredients; bioenergy; compost; circular bioeconomy; sustainable valorization

BIOCHEMICAL AND ANTIMICROBIAL PROFILING OF CAROB (CERATONIA SILIQUA L.) ORGANS FROM MOROCCAN POPULATIONS

Hasna ZAGGOUMI
Laboratory of Agro-Industrial and Medical Biotechnologies, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco.

Said BOUDA
Laboratory of Agro-Industrial and Medical Biotechnologies, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco.

Imane NEG
Laboratory of Agro-Industrial and Medical Biotechnologies, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco.

Ibtissam MARDOUME
Laboratory of Agro-Industrial and Medical Biotechnologies, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco.

Doha BELKACHACH
[b] Laboratory of Microorganisms and Active Biomolecules, Sciences Faculty of Tunis, University Tunis El-Manar. Tunis, Tunisia

Sonia MARGHALI
[b] Laboratory of Microorganisms and Active Biomolecules, Sciences Faculty of Tunis, University Tunis El-Manar. Tunis, Tunisia

Abdelmajid HADDIOUI
Laboratory of Agro-Industrial and Medical Biotechnologies, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco.

Abstract

Carob (Ceratonia siliqua L.) is a widely distributed Mediterranean tree with strong ecological adaptability and increasing interest as a natural source of bioactive ingredients. This study comparatively evaluated the biochemical and microbiological profiles of seeds, pulp, and leaves from six Moroccan carob populations originating from contrasting environments. Total polyphenols, flavonoids, and tannins were quantified, and antioxidant potential was determined using DPPH and FRAP assays. Antimicrobial activity was examined against Bacillus subtilis, Staphylococcus aureus, Escherichia coli, and Klebsiella pneumoniae using disk diffusion and microdilution approaches. Significant inter-population and inter-organ differences were recorded for all measured parameters. Pulp and leaves displayed the highest polyphenol contents, while seeds showed the strongest antioxidant and antimicrobial responses. Multivariate classification revealed marked diversity among populations and suggested that environmental and geographic factors contribute to population clustering. Overall, these results demonstrate that Moroccan carob exhibits valuable biochemical variability and provides effective natural antioxidant and antimicrobial agents. The species represents a promising plant

resource for developing sustainable, plant-based additives and functional ingredients suitable for food, environmental, and health-related applications.

Keywords: *Ceratonia siliqua*, natural antioxidants, antimicrobial activity, polyphenols, food ingredients, food technology

MICROENCAPSULATION OF *DYSPHANIA AMBROSIOIDES* ESSENTIAL OIL: AN EXAMPLE OF SUSTAINABLE VALORIZATION OF MOROCCAN NATURAL HERITAGE

Amal Dagni

Souraya Sakoui

Abdelaziz Soukri

Bouchra El Khalfi

Laboratory of Health, Environment and Biotechnology, Faculty of Sciences Ain Chock, Molecular Genetic Physiopathology and Biotechnology Team, Hassan II University of Casablanca, Maarif BP 5366, Casablanca, Morocco

Abstract

Dysphania ambrosioides is a wild plant native to Morocco, renowned for its rich ethnobotanical heritage and associated biodiversity. Its essential oil (EO) exhibits remarkable antibacterial and antioxidant properties, but its use remains limited due to its high volatility and instability.

In this study, we explored the sustainable valorization of this natural resource through its microencapsulation with natural biopolymers (inulin and gum arabic), known for their biodegradability and environmental safety.

The resulting microcapsules were characterized using various analytical techniques (FT-IR, SEM, TGA) to evaluate their stability, encapsulation efficiency, and behavior under simulated digestion.

The results show high encapsulation (88%), stability exceeding 80%, and controlled release of bioactive compounds. Furthermore, these microcapsules retained antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*. This research illustrates how the scientific valorization of a local plant contributes to preserving and promoting Moroccan biodiversity, while also opening up prospects for sustainable applications in the food, environmental, and heritage sectors.

Keywords : Microencapsulation, *Dysphania ambrosioides,* natural heritage, environment

APPLICATION OF THE NORMALYSA TOOL FOR RADIATION DOSE CALCULATION IN THE SEMI-ARID MEKNES AGRICULTURAL REGİON

Samira EL AOUIDI
Centre National de l'Energie, des Sciences et des Techniques Nucléaires – Rabat, Morocco

Zineb ELABOUDI
Process Engineering and Environment Laboratory (LGPE). Faculty of Sciences and Techniques of Mohammedia (FSTM). University of Hassan II Casablanca, Morocco

Abdelmourhit LAISSAOUI
Centre National de l'Energie, des Sciences et des Techniques Nucléaires – Rabat, Morocco

Radouan SAADI
Centre National de l'Energie, des Sciences et des Techniques Nucléaires – Rabat, Morocco

Azzouz BENKDAD
Centre National de l'Energie, des Sciences et des Techniques Nucléaires – Rabat, Morocco

Zineb EL Mouridi
National Institute of Agronomic Research (INRA), BP 6356, CRRA Rabat, Av. Al Irfane, 10100 Rabat, Morocco

Abstract

In this study, we used the NORMALYSA tool to simulate the effective radiation dose to humans based on soil-plant transfer factors obtained from two sampling campaigns in 2022 and 2023 in the Meknes agricultural area, as part of the international research coordinated project led by the International Atomic Energy Agency, CRP K41022. This simulation provides an estimate of radiation doses transferred from soil to plants, helping to assess potential exposure levels in the studied areas.

The total annual doses were calculated for 12 fields in the Meknes region for adult population (barley and wheat; bean; calabash; corn; eggplant and long cucumber; green and red pepper; potato; pomegranate; eggplant and tomato; red pepper; onion; cardoon and beet) for the adult population. In this scenario, exposure doses were calculated using four NORMALYSA models: "Garden plot," "Dose from ingestion of garden foods," "Dose from outdoor occupancy," and "Total dose."

The results show that the dose from outdoor external exposure is very low or even negligible in all fields studied. Similarly, the doses related to soil ingestion and ingestion of all garden food types are zero for all crops. In contrast, inhalation appears as the dominant exposure pathway to ionizing radiation among adults in these agricultural areas. However, it is important to emphasize that although the inhalation dose predominates compared to other pathways, it remains below the recommended limit of 1 millisievert per year (0.001 Sv/year), which is the maximum dose advised for the general population by radioprotection organizations.

Keywords: NORMALYSA tool, dose simulation, soil-plant transfer factors, Meknes semi-arid agricultural area

ASSESSING SOIL PROPERTIES AND FEMALE FARMERS PERCEPTION OF GULLY EROSION CONTROL STRATEGIES IN KALTUNGO LOCAL GOVERNMENT AREA, GOMBE STATE NIGERIA

Saleh Amina Bakaro

Department of Environmental Management and Toxicology, Faculty of Physical Sciences, Federal University Dutse.

Suleiman Ammar Muhammad

Department of Environmental Management and Toxicology, Faculty of Physical Sciences, Federal University Dutse.

Hassan Umar Ibrahim

Department of Environmental Management and Toxicology, Faculty of Physical Sciences, Federal University Dutse.

Abstract

Soil erosion, particularly gully erosion, remains a critical global environmental issue with profound implications for land productivity, water quality, and socio-economic stability. In Nigeria, gully erosion poses an increasing threat, particularly in the northern and southeastern regions, where deforestation, overgrazing, and unsustainable agricultural practices accelerate land degradation. Kaltungo Local Government Area (LGA) of Gombe State is among the areas severely affected, as its steep slopes, sparse vegetation, and intense seasonal rainfall contribute to rapid gully formation. Despite various control measures introduced by both governmental and non-governmental initiatives, erosion interventions in Kaltungo have often failed due to insufficient understanding of soil characteristics and inadequate stakeholder involvement, particularly the exclusion of women from erosion management efforts. This study aims to assess the physical and chemical properties of soils in gully-affected areas of Kaltungo LGA and to explore women's perceptions and participation in erosion control strategies. Soil samples were collected and analyzed to determine key parameters influencing erodibility, while structured questionnaires and interviews were conducted to capture women's experiences and viewpoints. The research integrates biophysical and socio-cultural perspectives to provide a comprehensive understanding of gully erosion dynamics. Findings from this study are expected to contribute to evidence-based erosion management by linking soil science with community participation, emphasizing gender inclusivity in environmental decision-making. Ultimately, the study will offer practical recommendations for sustainable land management and inform policy directions that strengthen the effectiveness and equity of erosion control strategies in Kaltungo and similar regions.

Keywords: Gully Erosion, Female famers, Kaltungo, Control strategies.

STUDY OF THE EFFECT OF *CISTUS MONSPELIENSIS* ON THE GENOMIC INTEGRITY OF SPERMATOZOA IN MALE RATS SUBJECTED TO LEAD TOXICITY

LADACI Hadjer

Animal Ecophysiology Laboratory, Department of Biology, Faculty of Sciences, Badji Mokhtar University–Annaba, Annaba 23000, Algeria

LOUDJANI Farida

Animal Ecophysiology Laboratory, Department of Biology, Faculty of Sciences, Badji Mokhtar University–Annaba, Annaba 23000, Algeria

LADOUALI Zineb

Animal Ecophysiology Laboratory, Department of Biology, Faculty of Sciences, Badji Mokhtar University–Annaba, Annaba 23000, Algeria

ABDENNOUR Cherif

Animal Ecophysiology Laboratory, Department of Biology, Faculty of Sciences, Badji Mokhtar University–Annaba, Annaba 23000, Algeria

ABSTRACT

Lead is a metal used by humans for millennia and is also a significant environmental pollutant. *Cistus monspeliensis*, a plant belonging to the Cistaceae family, is widely known for its medicinal properties. This experimental study was conducted on 20 adult male rats divided into four groups: Group 1—control (T); Group 2 (CM)—received 500 mg/kg b.w. of an infusion prepared from fresh *Cistus monspeliensis* leaves; Group 3 (Pb)—treated with 100 mg/kg b.w. of lead acetate diluted in distilled water; and Group 4 (CM + Pb)—co-treated with both agents, all administered by gavage for 4 weeks. At the end of the treatment period, the animals were sacrificed by decapitation. Sperm samples were collected to assess sperm DNA fragmentation.The results showed that the percentage of spermatozoa with intact DNA significantly decreased in rats treated with Pb compared with both the control group (T) and the positive control (CM). However, co-treatment with CM and Pb (CM + Pb) resulted in an increase in the percentage of non-fragmented sperm DNA compared with Pb-treated rats. Conversely, the percentage of spermatozoa with fragmented DNA was significantly higher in the Pb group compared with all control groups. A marked reduction in this percentage (fragmented DNA) was observed in the combination group (CM + Pb) compared with rats treated with Pb alone.In conclusion, lead increases DNA damage, whereas *Cistus monspeliensis* infusion reduces sperm DNA fragmentation and mitigates lead-induced oxidative damage at the spermatozoal level.

Keywords: Rat, *Cistus monspeliensis*, DNA, epididymis, spermatozoa.

EXPLORING PHYTASE PRODUCTION FROM MICROALGAE AND ITS INDUSTRIAL APPLICATIONS

Gowridevi V

Department of Biotechnology, Faculty of Science and Humanities, SRM Institute of Science and Technology, Ramapuram Campus, Chennai- 600089, Tamil Nadu, India.

S. Suresh

Department of Biotechnology, Faculty of Science and Humanities, SRM Institute of Science and Technology, Ramapuram Campus, Chennai- 600089, Tamil Nadu, India.

ORCID ID: 0000-0001-7706-7623

Murugesan Kamaraj

Department of Biotechnology, Faculty of Science and Humanities, SRM Institute of Science and Technology, Ramapuram Campus, Chennai- 600089, Tamil Nadu, India.

ORCID ID: https://orcid.org/0000-0002-0111-8524

Abstract:

Phytase is a crucial plant-based enzyme that is essential for breaking down the anti-nutritional factor Phytic acid present in plant-based foods. Phytase has numerous applications ranging from Agricultural (Animal feed), environmental (bioremediation) to pharmaceutical (Protein purification for Vaccine development, increasing the mineral bioavailability in the body, etc.). Currently, the Industrial production of Phytase to meet its ever-rising demand is mainly done using several Bacterial and Fungal strains as sources. But more innovative and sustainable practices can be adopted. One such idea is the production of Phytase from other microbial sources, like microalgae. Microalgae are currently in demand for their promising applications in the food and feed industries and in environmental and bioprocess applications. Because of their ability to utilize organic phosphorus sources for their metabolism, ease of obtaining a higher biomass yield, and their enhanced potential to express recombinant genes, microalgae are a promising source for producing Phytase. Microalgal species like *Chlamydomonas reinhardtii*, *Euglena gracillis*, *Phaeodactylum tricornutum* have been explored for their potential to express native and recombinant phytase. Thus, microalgae with their natural ability to hydrolyze organic phosphorous and metabolic versatility are a promising source to produce a sustainable, economical, and commercially scalable phytase enzyme.

Keywords: Phytase enzyme, Recombinant enzyme expression, Microalgae, Food and Feed industries, Bioremediation

FIRST WINTER BREEDING LIFE HISTORY TRAITS OF THE PLAIN TIGER BUTTERFLY, *DANAUS CHRYSIPPUS* (LINNAEUS, 1758) (LEPIDOPTERA: DANAIDAE) THROUGHOUT THE WINTERING PERIOD ON SONADIA ISLAND, BANGLADESH

Md. Shahinur Islam
Radiation Entomology and Acarology Division, Institute of Food and Radiation Biology, Atomic Energy Research Establishment, GPO Box-3787, Dhaka-1000, Bangladesh

Md. Mosharraf Hosain
Radiation Entomology and Acarology Division, Institute of Food and Radiation Biology, Atomic Energy Research Establishment, GPO Box-3787, Dhaka-1000, Bangladesh

Akira Yamanaka
Department of Applied Molecular Bioscience, Graduate School of Medicine, Yamaguchi University, Yoshida, Yamaguchi, Japan

A. T. M. F. Islam
Radiation Entomology and Acarology Division, Institute of Food and Radiation Biology, Atomic Energy Research Establishment, GPO Box-3787, Dhaka-1000, Bangladesh

Abstract

The monarch butterfly (*Danaus chrysippus*) is commonly known as the plain tiger butterfly, which is a short- and long-distance migrant butterfly. The breeding activities of plain tiger butterflies are well known in the summer season (March to October), but in winter (November to February), when temperatures fall, there are no records of breeding in. We surveyed host plants of plain tiger butterflies in January and February in the years of 2020 and 2021. In the main land regions, no breeding activities were found in the winter season. Overwintering (November to February) broods were observed and recorded on isolated coastal Island of Sonadia , Cox's Bazar that are the southern part of Bangladesh. This island is about 7-9 square kilometres in area and located at latitude 21.28″-21.33″ and longitude 91.50″-91.56″. The breeding area is characterised by milkweed plants, which are their primary host, and the presence of ambient day time temperature (28°C to 30°C). On the other hand, mainland day time temperature was 19°C to 20°C. We studied morphological characteristics of developmental stages, pupal colour, sex ratio, and cumulative mortality in larval stages of this species. The incubation period was 3.62±0.52 days. The larvae and pupae durations were 18.18±0.94 days and 10.66±1.11 days. The male longevity was 9.0–43 days, and the female was 14.0–66.0 days. The mortality rate of the second, third, and fourth instar larvae was 2.77%, 2.85%, and 3.70%, and the mortality rate in pupae was 11.58%. Out of 23 pupae, pink was 82.61%, and brown was 17.39%. The sex ratios, regardless of the colour of pupa, showed 12 males (52.18%) and 11 females (47.82%) were found from green and pink coloured pupae. Male was predominated in pink colour (91.66%), and female (63.64%) also had a prevalence of pink colour. The findings of this study could be useful for predicting the population dynamics and help to develop appropriate conservation strategies for this species. This is the first study to document with the winter breeding life history of the plain tiger butterfly from the coastal part of Bangladesh.

Keywords: Overwintering life cycle, Plain tiger, *Danaus chrysippus*, Lepidoptera, Danaidae, Sonadia Island

BUMBLEBEE PARASITES TRANSMITTED TO HONEYBEES - *APICYSTIS BOMBI*

Academician prof Dr Ivan PAVLOVIĆ

Scientific Institute of Veterinary Medicine of Serbia, Belgrade, Serbia

ORCID ID:https://orcid.org/ 0000-0003-4751-6760

ABSTRACT

Introduction and Purpose: It is known that a greater number of pathogens are transmitted between bumblebees and honey bees.Its including viruses, bacteria, fungi and protozoa. After acting as incidental hosts, honey bees may become the primary maintenance host, as occurred in the cases of *Apicystis bombi. A.bombi* is a unique apicomplexan protist that belongs to the neogregarines, which as a group exhibit relatively high virulence towards a range of insects.

Materials and Methods: Microscopic examination of the tissue is required to confirm the presence of oocysts. Other than the fat body, oocysts have been detected in the midgut and hindgut body parts of bees and in a single case in the spermatheca of a mated bumble bee and honey bee queen.

Results: It infects bees, especially bumblebees. It is believed to have a cosmopolitan distribution in bumblebees and a sporadic occurrence in honey bees, and causes disease symptoms in nonresistant bee species.

Discussion and Conclusion: *A. bombi*'s host range spanning *Apis* and *Bombus* may indicate that they are sharing gregarines at the shared pollen source. Oocysts are ingested by the bee and sporozoites develop from these in the intestine. They migrate through the wall of the gut before taking up residence in the fat body cells, where they develop and multiply. Typically , healthy fat body cells appear yellow while heavily infected cells appear swollen and distinctly white as a result of hypertrophism. The effects of *A.bombi* differ between host species. Heavily infected bees are rare, but this may be due to high pathogenicity of the neogregarine. Infected bee workers have increased mortality, reduced fatbody and increased sensitivity to sucrose. Infected queen bumblebees are unlikely to survive hibernation which is thought to be due to the reduced fatbody of infected queens. There is also some evidence that DWV (Deformed wing virus) may reduce some of the negative effects of *Apicystis bombi*.

Key Words: honey bee, bumblebee, *Apicystis bombi*

VARIABILITY OF POLLEN COLLECTED BY *APIS MELLIFERA INTERMISSA* BEES IN A MOUNTAINOUS REGION OF ALGERIA

Dr. Fatima DJOUBER-TOUDERT

Department of Agronomy, University Mouloud Mammeri Tizi-Ouzou, Algeria

Pr. Messaouda BELAID

Department of Process Engineering, University M'Hamed Bougara Boumerdès, Algeria

ABSTRACT

Introduction and Purpose: Honey constitutes only a fraction of the valuable products derived from the beehive. Other honeybee's products, such as royal jelly, beeswax, propolis, venom, and pollen, also possess significant biological and ecological properties. Among these, pollen plays a particularly critical role within the colony, serving as the principal source of proteins essential for brood development and overall colony health. Numerous studies have been conducted to determine its chemical composition, evaluate the role of bees in pollination, and establish the palynological profile of specific regions. The present study aims to analyze the variability of plant species foraged by honeybees and to identify melliferous flora in a mountainous region of Algeria.

Materials and Methods: An experimental setup involving 10 beehives was established. The breed of honeybees was *Apis mellifera intermissa* or Tellian honeybees. Pollen traps were installed at the hive entrances, and pollen collection was carried out once a week over one month period. The collected samples were air-dried, cleaned, and stored in labeled containers until analysis. Pollen identification was performed using standard microscopic techniques. Morphological characteristics of the pollen grains were compared with those presented in published pollen atlases and with reference slides prepared and maintained by our laboratory.

Results: Analysis of the collected pollen revealed the presence of 14 distinct color types. The number of pollen colors per sample ranged from a minimum of three to a maximum of 10. Orange-colored pollen was the most abundant (17%), whereas beige-colored pollen was the least represented (11%). A total of 29 melliferous plant species, belonging to 17 botanical families, were identified as pollen sources.

Discussion and Conclusion: This study underscores the richness and diversity of floral resources available to honeybees in the study area. Such diversity not only contributes to bee nutrition and colony sustainability, but also highlights the ecological importance of preserving native plant habitats. The conservation of these floral resources is essential for maintaining pollinator populations and, by extension, the biodiversity and resilience of ecosystems.

Keywords: Honeybees, palynology, melliferous plants, *Apis mellifera intermissa*, pollen.

SYNERGISTIC EFFECTS OF PLANT HORMONES AND HERBICIDES

Assoc. Prof. Dr. Emine KAYA ALTOP

Ondokuz Mayıs University, Faculty of Agriculture, Department of Plant Protection, Samsun, Turkiye

ORCID ID: https://orcid.org/0000-0002-0987-9352

Ph.D. Sine KAYA

Ondokuz Mayıs University, Graduate School of Natural and Applied Sciences, Department of Plant Protection, Samsun, Turkiye

ORCID ID: https://orcid.org/0000-0002-4219-9148

ABSTRACT

Plant hormones and herbicides working together synergistically is a potential new frontier for environmentally friendly weed management. Basically, hormones regulate the plants' physiological and biochemical processes that impact their growth, ability to resist stresses, and detoxification mechanisms, whereas herbicides are designed to inhibit the biochemical pathways that lead to weed growth. Experiments on the matter have shown that in some cases, substances like abscisic acid (ABA), brassinosteroids (BRs), and jasmonic acid (JA) may, under certain conditions of concentration, timing, and species, facilitate or hinder the action of herbicides. The main benefit of such interplays is the possibility of achieving higher selectivity, lower doses of herbicides, and less harm to crops. This article reviews the current understanding of the phenomenon of hormone–herbicide synergy, emphasizing the aspects of molecular signaling cross-talk, physiological changes, and integrated weed management implications.

Keywords: Herbicide Synergy, Plant Hormones, Phytohormone Regulation, Detoxification, Integrated Weed Management, Brassinosteroids, Abscisic Acid

INTRODUCTION

Herbicides have been the main tools for weed management. They have facilitated a quick and effective suppression of weeds in the agricultural practice of recent years. Nevertheless, the heavy and repetitive use of herbicides has caused a series of negative effects, such as pollution of the environment, emergence of herbicide-resistant weed populations, and unintentional phytotoxicity of crops (Heap, 2023; Duke, 2012). As a result of the drawbacks, the scientific community has been motivated to search for novel strategies that can both elevate the efficacy of herbicides and lessen the risks to the environment. One of the promising pathways in such direction is the use of hormones to modulate the physiological responses of plants (Grossmann, 2010).

Plant hormones or phytohormones are small molecular weight signaling compounds that regulate an immense number of processes related to growth and resistance. These are auxins,

cytokinins, gibberellins, abscisic acid (ABA), ethylene, salicylic acid (SA), jasmonates (JA), and brassinosteroids (BRs). The network of the eight hormones controls plant growth, the release of the defense system and resistance to both abiotic and biotic stresses (Santner & Estelle, 2009). Moreover, researchers have found that the same signaling pathways can communicate with herbicide-induced stress, thereby affecting the mechanisms of both sensitivity and resistance (Silva et al., 2009).

Synergy here means a scenario where the joint effect of a herbicide and a hormone exceeds the sum of their single effects. In support of this, one study found that some hormone pre-treatments can facilitate herbicide uptake, movement within the plant, and efficiency at the target site (Manghwar et al., 2022). On the other hand, certain hormones are capable of lessening the oxidative and metabolic stress brought about by herbicides, thus making the crops free of injury and at the same time, retaining the functionality of the herbicide for weed control (Sandalio et al., 2023). The two-faced operation of the hormones, i.e. either to activate the herbicidal effect to non-target plants or to provide a defense mechanism, depends upon hormone kind, dose, and the time of application.

It is possible that information about the molecular and physiological bases of such interactions might lead to the best use of herbicides for less environmental harm. One of the advantages of incorporating hormonal control into chemical weed management is the possibility to lessen the dependence on herbicides, prolong the time before resistance to herbicides appears, and enhance the safety of crops (Silva et al., 2009). Furthermore, the advent of "green chemistry" and the use of plant growth regulators have brought about several new possibilities in this area, one of which is the exploitation of inherent plant signaling for weed suppression and stress tolerance.

Hence, this paper's objectives are to:

- Illustrate the foundational aspects of herbicide mechanisms and plant hormone regulation.
- Discuss instances where hormone and herbicide interactions have a synergistic effect.
- Illustrate the molecular dialogue and metabolic regulation involved in these interactions.
- Point out the missing pieces of knowledge and the directions of future research that aim at exploiting this synergy in the context of contemporary weed management strategies.

CLASSIFICATION AND MODES OF ACTION OF MAJOR HERBICIDES

Herbicides are chemicals that are mainly intended to do the task of controlling or getting rid of unwanted plants by radically interfering with their vital physiological or biochemical pathways (Dayan & Duke, 2014). They are divided into different major groups based on their chemistry and site of action, with each group consisting of agents that target certain enzymes or cellular processes. The fundamentals of these scenarios should be agreed upon first before we can understand to what extent plant hormones play a role in indorsing or modifying herbicides' action.

Major Classes of Herbicides

The top herbicides are considered as a single group depending on their mode of action (MoA). The Herbicide Resistance Action Committee (HRAC) segregates herbicides into over 30 MoA groups, but only a handful of them are prevalent in worldwide farming (HRAC, 2023).

1. Photosystem II (PSII) inhibitors (e.g., atrazine, diuron) block electron flow in the photosynthetic process, thereby creating oxygen radicals (ROS) that damage lipids of the cell organelle membrane (Dayan et al., 2014).

2. Acetolactate synthase (ALS) inhibitors (e.g., imazapyr, metsulfuron-methyl) prevent the making of branched-chain amino acids which stops the proteins synthesis and cell division (Yu & Powles, 2014).

3. Acetyl-CoA carboxylase (ACCase) inhibitors (e.g., fenoxaprop, quizalofop) block the production of fatty acids in grasses that lead to membrane damage and energy metabolism changes (Délye, 2013).

4. 5-Enolpyruvylshikimate-3-phosphate (EPSPS) inhibitors, like glyphosate, bind and block the shikimate pathway, thus, aromatic amino acids are not produced (Duke & Powles, 2008).

5. Protoporphyrinogen oxidase (PPO) inhibitors (e.g., oxyfluorfen, saflufenacil) prevent chlorophyll formation, thus, the plant experiences oxidative stress and tissue death occur rapidly (Matringe et al., 2020).

6. Synthetic auxins (e.g., 2,4-D, dicamba) are structurally and functionally similar to the natural auxin (IAA), hence, growth becomes uncontrollable, and cells keep on expanding ultimately the plant dies (Grossmann, 2010).

7. Mitotic inhibitors (e.g., trifluralin, pendimethalin) stop microtubules from lengthening, thus, the process of cell division in mitosis is interrupted (Heap, 2008).

The discussed herbicide categories differ from one another by factors such as selectivity, persistence, and spectrum of control. Their performance and the degree of crop safety may be highly determined by the interplay of various environmental factors and the physiological state of the plants, which is under the control of hormones (Silva et al., 2009) (Table 1).

Table 1. Major Classes of Herbicides and Their Modes of Action

Herbicide Class	Example Compounds	Mode of Action	Target Enzyme / Site
ALS inhibitors	Bispyribac-sodium, Imazapyr	Inhibit acetolactate synthase (ALS)	ALS enzyme
ACCase inhibitors	Clodinafop, Fenoxaprop	Inhibit acetyl-CoA carboxylase	ACCase enzyme
Photosystem II inhibitors	Atrazine, Diuron	Block electron transport in PSII	D1 protein of PSII
EPSPS inhibitors	Glyphosate	Inhibit 5-enolpyruvylshikimate-3-phosphate synthase	EPSPS enzyme
Synthetic auxins	2,4-D, Dicamba	Disrupt auxin signaling and growth	Auxin receptor / Auxin pathways
Photosystem I inhibitors	Paraquat, Diquat	Generate reactive oxygen species (ROS)	Photosystem I
PPO inhibitors	Fomesafen, Oxyfluorfen	Inhibit protoporphyrinogen oxidase	PPO enzyme

Physiological Impact of Herbicide Action

Herbicides are the cause of a series of unfortunate events in a plant's defensive system. They eventually lead to the production of highly reactive oxygen species, disruption of the hormonal balance, and several other changes in the metabolic signaling that were they to be studied separately, each would warrant a paper of its own. For instance, Grossmann and Kwiatkowski (1999) have demonstrated that application of ALS inhibitors leads to an increase in the amount

of the plant hormones abscisic acid (ABA) and ethylene and thus, as a consequence, the stomata close and growth slows down. Likewise, glyphosate exposure results in the increase of salicylic acid (SA) and jasmonic acid (JA) and hence, the conversion of these compounds initiates the defense-related systems that are usually activated by attacks of living organisms (Velini et al., 2008).

The ROS wave brought about by herbicides like paraquat or PSII inhibitors results in the activation of antioxidant proteins, such as superoxide dismutase (SOD) and catalase (CAT). The activity of these enzymes is regulated by hormonal cross-talk, mainly by brassinosteroids and ABA (Sandalio et al., 2023). The degree to which the tissue is damaged as a result of the herbicides' action depends not only on the inherent toxicant potency of the herbicide, but also on the hormones present in the plant that are capable of counteracting the harm.

Hormonal Cross-Talk in Herbicide Response

Plant hormones are vital in the processes through which the plants respond to the application of herbicides. Synthetic auxin herbicides forcibly employ auxin (IAA)-signaling pathways, however, other herbicides influence hormonal balance indirectly. For instance, cytokinins and gibberellins help the cell division process and the elongation of cells that in turn may be the reason for the overshooting of the herbicide-induced growth inhibition. In contrast, ABA and ethylene are typical components that become more abundant as a result of the transmission of the stress signal, whereas the roles of brassinosteroids and jasmonates are in the processes of detoxification and repair (Silva et al., 2009). The described communication implies that the alteration of the hormonal concentration before or after the herbicide treatment may have an impact on the plant’s sensitivity or tolerance to it; this is the core idea involved in the synergy between herbicide and hormone.

Generally, the action of an herbicide determines which organelle or molecule in a cell will be toxicologically affected, while hormonal intervention governs the physiological response of the plant. Developing such applications that exploit the interrelations on the molecular level is crucial to the synergistic optimization of herbicides' working capacity along with the least possible crop injuries.

OVERVIEW OF PLANT HORMONES AND THEIR ROLES

Plant hormones, also known as phytohormones, are organic compounds of natural origin that essentially govern a plant's growth, its developmental processes, and even the plant's reaction to various kinds of stress, all this at very low levels of concentration. These signaling molecules are responsible for coordinating a network of physiological and biochemical processes which basically serve as the plant's internal communication system, integrating signals that come from inside the plant as well as from the environment (Davies, 2010). The major groups of plant hormones are auxins, cytokinins, gibberellins, abscisic acid, ethylene, jasmonates, salicylic acid, and brassinosteroids. However, to complicate things, hormones do not always function separately. On many occasions, they form a complex web of cross-regulatory interactions that affect herbicide sensitivity as well as detoxification mechanisms.

Auxins

Auxins are the first discovered class of plant hormones, and among them, *indole-3-acetic acid* (IAA) is considered the major natural one. They are the regulators of cell elongation, apical dominance, and vascular differentiation (Woodward & Bartel, 2005). Mimicking IAA, synthetic auxins like 2,4-dichlorophenoxyacetic acid (2,4-D) and dicamba are generally used

as selective herbicides (Grossmann, 2010). These agents deliberately provoke uncontrolled cell elongation, abnormal vascular development, and disintegration of tissues in broadleaf weeds. On the other hand, auxins present in the organism also influence the herbicide transport that is, they help by regulating the expression of auxin transporters (PIN proteins) and ABC transporters which in turn affect herbicide translocation (Silva et al., 2009).

Cytokinins

Cytokinins are adenine derivatives, which, among other things, promote cell division, delay senescence, and interact antagonistically with auxins in organ development (Kieber & Schaller, 2018). In the first place, they are the main players in nutrient mobilization and chloroplast development. Upon herbicide stress, the cytokinin level is usually depleted, thus resulting in accelerated senescence and chlorosis . The external supply of cytokinins has been reported to relieve the herbicide-induced oxidative damage and facilitate the recovery phase by triggering antioxidant enzyme activities. Therefore, cytokinins may be deployed as a kind of shield for herbicide-affected crops.

Gibberellins

Gibberellins (GAs) are, in fact, diterpenoid acids that provide the main impetus for stem elongation, seed germination, and flowering (Yamaguchi, 2008). Most of their effects come via the GA–GID1 receptor complex that removes the DELLA proteins, which are growth repressors. Herbicides which lead to inhibition of amino acid or fatty acid biosynthesis may lower the level of GA, consequently causing dwarfism and delayed growth (Sandalio et al., 2023). In some cases, GA applications, to a certain extent, can not only bring back the plant's normal growth but also fight against herbicide toxicity by facilitating metabolic recovery .

Abscisic Acid (ABA)

Among its diverse functions, ABA can be characterized as a main stress hormone as it regulates stomatal closure, seed dormancy, and tolerance towards non-living stress factors. It is a substance that is very scarce under natural conditions but accumulates very rapidly under drought, salinity, or stress from chemicals (Cutler et al., 2010). In many cases, herbicide exposure can be regarded as one of the factors that cause an increase in ABA biosynthesis in the oxidative-stress-defense response (Grossmann & Kwiatkowski, 1999). What is more, an externally applied ABA pretreatment can certainly lead to great performance of crops in the presence of herbicide products such as paraquat or glyphosate by modulating the antioxidant defense and detoxification pathways (Manghwar et al., 2022). Still, too much ABA can have a growth-inhibitory effect thus emphasizing the necessity of the right dose and time in hormone–herbicide cooperation.

Ethylene

Being a nonmetallic gas, ethylene is responsible, among others, for senescence, fruit ripening, and the sharing of stress signals. The synthesis of this molecule through the methionine–ACC (1-aminocyclopropane-1-carboxylic acid) pathway is very fast and gets induced by herbicide-caused stress (Morgan & Drew, 1997). One of the reasons for leaf epinasty, chlorosis, and abscission is the increased ethylene production resulting from the treatment with assistants for ALS or synthetic auxins like 2,4-D (Grossmann, 2010). On the other hand, ethylene may also play a saving role if it triggers detoxification enzyme and stress-related gene activation (Abeles et al., 1992). The double status of ethylene, as both a symptom and a modulator of herbicide stress, places it as a critical hormone in herbicide response.

Jasmonates and Salicylic Acid

Jasmonic acid (JA) and salicylic acid (SA) are the key elements in the control of plant defense systems. JA mainly works through the response mechanism against mechanical injury and insect feeding, whereas SA is related to systemic acquired resistance (Wasternack & Hause, 2013). When plants are subjected to herbicide application, the levels of JA and SA in the tissue become higher, thus most likely leading to the implementation of antioxidant systems and the activation of detoxification-related genes (Sandalio et al., 2023). The interaction between JA, SA, and ABA signaling pathways helps the plant oxidative stress response to be more precise. Many studies have shown that JA pretreatment led to increased tolerance to paraquat and atrazine, thus suggesting a hormone-herbicide synergistic relationship.

Brassinosteroids

Brassinosteroids (BRs) are biologically polyhydroxysteroids structurally resemble animal steroids and are very important for cell expansion, vascular differentiation, and acclimation to stress (Clouse & Sasse, 1998). BRs are very potent antioxidants as they not only regulate ROS homeostasis but also increase the activity of detoxification enzymes like glutathione S-transferases (GSTs) (Nakashita et al., 2003). The removal of pollutant-induced oxidative injury by the exogenous treatment of 24-epibrassinolide (EBR) has been documented in research on rice and wheat that also observed a rise in selectivity (Manghwar et al., 2022). The current finding points to the potential of BRs as synergistic agents in herbicide formulations.

Hormonal Cross-Talk

Most of the times, plant hormones do not function separately; they rather build up complex networks through signaling cross-talk. To give an example, the interaction between ABA and JA results in a strong oxidative stress defense whereas the interplay between auxin and cytokinin determines cell division and tissue regeneration (Kieber & Schaller, 2018). Zhao & Li (2020) have found out that on the one hand, brassinosteroids usually work together with auxin and gibberellins to stimulate growth and, on the other, they act as foes to the ABA during the occurrence of a stress situation. The concept of dynamic hormonal interplay tells us that these interactions among different plant hormones are the very root of how plants detect and counteract herbicides, thus they can be either susceptible or tolerant.

One by one the phytohormones and collectively as well, they are the regulators of the most fundamental growth and stress mechanisms that have a large impact on herbicide responses. Their potentiality to govern detoxification, being in oxidative balance, and turning to growth for recovery is the biochemical basis that allows one to look into hormone–herbicide synergy as a new dimension in the modern weed management systems (Table 2).

Table 2. Key Plant Hormones and Their Physiological Functions

Hormone	Main Physiological Roles	Response to Stress / Herbicide
Abscisic Acid (ABA)	Stomatal closure, drought tolerance, seed dormancy	Induces antioxidant enzymes, enhances herbicide tolerance
Jasmonic Acid (JA)	Defense signaling, wounding response, growth inhibition	Activates GSTs and ROS scavenging under herbicide stress
Salicylic Acid (SA)	Systemic acquired resistance, pathogen defense	Modulates redox balance and detoxification, can enhance or reduce herbicide effects
Brassinosteroids (BRs)	Cell elongation, division, stress tolerance	Upregulate detox enzymes and ABC transporters, improve herbicide selectivity
Auxins (IAA)	Cell division, elongation, tropic responses	Modifies synthetic auxin herbicide sensitivity, can enhance or antagonize effects
Cytokinins	Cell division, shoot initiation	Can mitigate growth inhibition caused by herbicides
Gibberellins	Stem elongation, seed germination	Limited evidence on herbicide interactions, may affect growth recovery

MOLECULAR BASIS OF HORMONE–HERBICIDE INTERACTIONS

The interaction of hormones and herbicides in plants at the cellular level is mainly about their interconnected molecular networks that control signal transduction, transcriptional regulation, and metabolic modulation. In fact, herbicides can alter the biosynthesis of hormones that affect not only signaling pathways but also the whole body's hormonal balance, while hormones affect herbicide absorption, detoxification, and target-site sensitivity. Understanding these molecular interactions paves the way for the implementation of the hormonal cross-talk concept, which can be either one of increasing herbicide efficacy or decreasing the phytotoxic side effects of the herbicide.

Hormone Signaling Pathways and Cross-Talk

Plant hormone signaling are basically a series of events from hormone perception to signal transduction that involve changes due to receptor-ligand interactions, secondary messengers, and transcriptional regulators (Santner & Estelle, 2009). The signaling pathways are not direct; rather, they are very much interconnected thus forming a highly dynamic signaling network which is responsible for plant responses both to environmental factors and to chemical agents (Depuydt & Hardtke, 2011).

An example of that is the way auxin signaling is done through the TIR1/AFB–Aux/IAA–ARF system, whereby auxin binding leads to the breakdown of the Aux/IAA repressors thereby granting the access of the auxin response factors (ARFs) to the promoter regions of the target genes (Leyser, 2018). The cytokinin signal is passed through the action of receptor histidine kinases and a two-component system, whereas the ABA signaling relies on PYR/PYL/RCAR receptors that, upon binding, lead to inhibition of PP2C phosphatases thus resulting in the activation of SnRK2 kinases (Cutler et al., 2010). All these systems have common points where they interconnect especially in the case of stress situations that come as a result of herbicide application (Silva et al., 2009).

Normally, the activation of ABA and jasmonate pathways is the cause of herbicides that lead to oxidative or osmotic stress, whereas auxin-like herbicides directly take advantage of auxin receptors (Grossmann, 2010). In a similar way, the use of glyphosate, an EPSPS inhibitor, is reported to have an impact on the salicylic acid (SA) and jasmonic acid (JA) signaling pathways with the end effect of changing the expression of genes related to plant defense (Vivancos et al., 2011). These kinds of hormonal changes have a significant effect on downstream detoxification and stress tolerance responses.

Transcriptional and Metabolic Reprogramming

On the transcriptional level, herbicides elicit a global reprogramming of gene expression that significantly overlaps with the networks of hormonal signaling. Transcriptomic experiments have shown that genes related to ABA, ethylene, and JA signaling are upregulated after treatments with ALS or PSII inhibitors (Sandalio et al., 2023; Silva et al., 2009).

For instance, exposure to imazapyr (an ALS inhibitor) results in the expression of *NCED3* (a major gene in ABA biosynthesis) and *ERF1* (ethylene response factor), which implies that herbicide stress leads to the activation of both the ABA and ethylene pathways . In a similar manner, the plants treated with glyphosate exhibit that *GSTs* and *CYP450s* expressions are upregulated. These are the enzymes that are responsible for xenobiotic detoxification and are under the regulation of jasmonate and brassinosteroid signaling (de Freitas-Silvaet al., 2017).

At the same time, metabolomic studies confirm that external application of brassinosteroids and abscisic acid not only changes herbicide metabolism but also influences glutathione conjugation and oxidative state of the cell (Manghwar et al., 2022). These hormones activate the antioxidative system of the crop, which is made up of superoxide dismutase (SOD), catalase (CAT), and ascorbate peroxidase (APX), thus, they reduce lipid peroxidation and membrane destruction (Nakashita et al., 2003). This molecular shield allows the crops to be free from herbicidal stress but still maintain the problem of weed control.

HORMONE REGULATION OF TRANSPORTERS AND DETOXIFICATION ENZYMES

At the cellular molecular level, the interaction of hormones with herbicides is mostly about how hormones regulate membrane transporters and enzymes that are engaged in detoxification. ABC transporters and multidrug resistance proteins (MRPs) are the primary characters when it comes to the cellular efflux of herbicides and their metabolites (Goldberg-Cavalleri et al., 2023). Hormones like auxins, ABA, and brassinosteroids are able to alter the formation of these transporters, which are the agents that help the substances to be pushed into different parts of the plant by changing their dispersal in the tissues, thus they facilitate the transport of the substances to any part of the plant (Silva et al., 2009).

For instance, BR signaling through the BZR1 transcription factor assists detoxification-related genes like *GSTU19* and *CYP81A6* in becoming more active in transcription (Manghwar et al., 2022). Similarly, ABA and JA promote the transcription of glutathione S-transferases (GSTs) and cytochrome P450 monooxygenases, which eventually contribute to herbicide metabolism and conjugation (Sandalio et al., 2023). On the contrary, ethylene can diminish the expression of certain transporter genes, thus, leading to the local accumulation of herbicides and resultant tissue damage (Morgan & Drew, 1997).

According to this, hormones serve as the main regulators of the cellular detoxification system that is a part of the metabolic network of the plant that is shifting to keep equilibrium under challenge with herbicides. The degree of the balance between the activation and the repression of these molecular responses can determine whether the synergistic enhancer effect of herbicide efficacy (in weeds) or crop protection against toxicity will be the case.

Signal Integration and Cross-Regulatory Nodes

The joining of several hormone signaling pathways with the response to herbicides is done with the help of the shared signaling intermediates such as reactive oxygen species (ROS), calcium ions (Ca^{2+}), and mitogen-activated protein kinases (MAPKs). ROS are the intermediate messengers that very often change the activity of transcription factors such as WRKY, MYB,

and NAC. At the same time, these are also the targets of hormone signaling (Mittler, 2017). To this end, herbicide-induced ROS generation canbe a very strong factor in amplifying the hormone responses, thus leading the organism either to stress tolerance or to inhibition of growth, depending on the hormonal context.

Another point at which MAPK cascades converge is the interaction between herbicide and hormone signaling. Both JA-mediated defense and herbicide-induced oxidative stress have been linked with the activation of MPK3 and MPK6 (Opdenakker et al., 2012). Besides, transcription factors such as TGA, DREB, and BZR1 that receive inputs from different hormones and chemical stress signals coordinate the gene expression changes that are necessary for adaptation (Depuydt & Hardtke, 2011; Silva et al., 2009).

Through these consolidated molecular circuits, the plant is capable of making a quick switch of its physiological and biochemical state in the case of herbicide challenge. If managed in the proper manner, this molecular synergy can serve the purpose of herbicide selectivity and can elevate their performance in the agricultural sector.

SYNERGISTIC EFFECTS BETWEEN HORMONES AND HERBICIDES

Plant hormone and herbicide synergistic interactions are an important instrument for the enhancement of efficiency in weed management, crop tolerance, as well as sustainability in agricultural systems. Synergism is an occurrence when the joint use of a plant hormone and a herbicide brings about a physiological effect which is higher as compared to the effect from either compound used alone. The main result of this interaction may be the increase in herbicide selectivity, crop stress tolerance, or weed resistance to herbicidal activity.

The main molecular and physiological mechanisms that underlie these synergistic effects are the modulation of plant growth regulators, detoxification systems, oxidative stress responses, and target-site sensitivity (Grossmann, 2010; Silva et al., 2009). The synergy effect can either enhance the herbicide's damaging potential to the target plants or reduce the toxic impact on non-target plants depending on the hormone and herbicide involved.

Auxin and Synthetic Auxin Herbicide Synergy

Auxin analog herbicides like 2,4-dichlorophenoxyacetic acid (2,4-D), dicamba, and picloram imitate directly the activity of auxins that are naturally present in plants, which results in uncontrolled cell elongation, epinasty, and tissue disintegration (Song, 2014). Nevertheless, there is not an outcome of straightforwardly additive effects from the interaction between natural auxins and synthetic auxin herbicides. The exogenous application of indole-3-acetic acid (IAA) at low levels is able to alter the plant's sensitivity to the action of auxin-like herbicides and it can either increase the toxicity or decrease it depending on the time and the dose.

As a result of auxin pretreatment, the plasma membrane in some weed species becomes more permeable, thus the absorption of herbicide is accelerated and consequently there is also a faster translocation and better efficacy (Neve et al., 2024). On the other hand, in tolerant crops, the normal functioning of auxin signaling is able to keep cells in a steady state and thus uncontrolled growth is prevented, so herbicide injury is at a minimum level. The existence of this hormone–herbicide synergy dose-dependent nature is demonstrated here by the dual behavior of the agents.

On a molecular basis, both IAA and 2,4-D ARF-mediated transcription networks are activated; nevertheless, detoxification-related genes like *GH3* and *GST* can have their expression primed by the auxin pretreatment, which results in a less auxin accumulation after herbicide exposure

(Silva et al., 2009). This process is in line with the conception that hormonal regulation being balanced is the factor deciding whether the auxin–herbicide interaction will lead to synergy or antagonism.

Abscisic Acid (ABA) and Herbicide-Induced Stress Tolerance

The abscisic acid (ABA) is instrumentally important in modulating the plant reaction to abiotic and chemical stressors by a number of mechanisms among which stomatal closure, antioxidant activity, and detoxification pathways are the major ones (Cutler et al., 2010). Several experiments have shown that the tolerance to the herbicide-caused oxidative stress can be imparted by the exogenous ABA pretreatment, in particular, to the plant tissue that is suffering from ALS inhibitors and photosystem II (PSII) blockers (Luo et al., 2020; Sandalio et al., 2023).

ABA, besides others, promotes the activities of the antioxidant enzymes such as SOD, CAT, and peroxidases, thus lessening the build-up of reactive oxygen species (ROS) that result from the stress application by herbicides (de Freitas-Silvaet al., 2017). In addition to that, ABA is also a strong inducer of glutathione production and glutathione S-transferase (GST) activity, thus herbicide detoxification is facilitated (Silva et al., 2009). Such a tandem between the two agents makes it possible for the likes of rice and maize to be resistant to herbicide treatments which would have resulted in chlorosis and growth retardation if these crops were not tolerant.

What is more, ABA is able to influence the uptake and the movement of the herbicide inside the plant via aquaporins as well as by the regulation of the plasma membrane integrity. To illustrate, ABA pretreatment prior to glyphosate application results in the herbicide being less mobile in phloem tissues, thus damage to the leaf areas that are sensitive is minimized . Hence, the protective synergy of ABA is mainly in the abatement of stress and in the regulation of metabolism rather than direct promotion of herbicide toxicity.

Brassinosteroids and Enhancement of Herbicide Selectivity

Brassinosteroids (BRs) are one of the most effective means to influence plant growth, development, and stress tolerance. A recent paper highlights that when plants are treated with BRs, they can tolerate herbicide assaults better by activating their antioxidant system, stabilizing their cellular membranes, and speeding up the repair of photosynthetic structures damaged by herbicides (Nakashita et al., 2003; Manghwar et al., 2022).

Lead application of 24-epibrassinolide (EBL) to cereal plants just before herbicide spraying was found to cause a considerable increase in the selectivity factor of crop vs. weed species (Manghwar et al., 2022). As an example, in rice and wheat, the pretreatment of the plants with BRs almost completely eliminated the phytotoxicity of sulfonylurea herbicides while at the same time the herbicide suppressive effect on weeds was left intact. The interaction results from BR-mediated induction of the BZR1–BES1 transcriptional cascade which in turn activates the detoxification (*CYP81A6, GSTU19*) and the antioxidative stress regulation (*SOD, APX*) related genes (Silva et al., 2009).

On top of that, brassinosteroids are regulating membrane-bound transporters like ABC proteins, thus increasing the secretion of herbicide metabolites from the most vulnerable parts of a plant (Goldberg-Cavalleri et al., 2023). The combination of biochemical protection and targeted detoxification actions makes brassinosteroids ideal candidates for manipulating the herbicide resistance trait in crops without losing the efficacy of weed control.

Jasmonates and Salicylic Acid in Modulating HerbicideResponse

Jasmonic acid (JA) and salicylic acid (SA) are essential elements of plant defense signaling networks, and their synergistic interaction with various herbicides has also been reported. A JA signaling pathway can elevate plant stress tolerance level after herbicide treatment by

stimulating the biosynthesis of secondary metabolites among which flavonoids and phenolics whose role is to scavenge ROS and thus repair cellular damage (Sandalio et al., 2023).

In contrast, SA may either alleviate or increase herbicide toxicity depending on its concentration and the time of application. The application of SA before paraquat exposure has been shown to relieve oxidative stress in soybean through the increase in activities of antioxidant enzymes (Silva et al., 2009). On the other hand, in some weed species, SA facilitates glyphosate action by enhancing shikimic acid accumulation and causing redox imbalance (Vivancos et al., 2011).

Usually, JA and SA work in opposition to each other in the defense against pathogens but in the case of chemical stress, their interaction is synergistic. Their combined impact on the detoxification process as well as on programmed cell death makes the determination of plant recovery or death after herbicide treatment possible (Mittler, 2017). Knowledge of these hormone–herbicide interactions is important for the best timing of pre- or post-treatment in crop protection.

Mechanistic Basis of Synergy

The mechanistic basis of hormone–herbicide synergies can be depicted as:

- Enhanced Detoxification: For example, ABA and BR induce expressions of GSTs, CYP450s, and ABC transporters, thus fastening herbicide metabolism (Manghwar et al., 2022).
- Antioxidant Activation: Auxins, JA, and BRs, for example, activate antioxidant enzymes, thus the oxidative damage caused by ROS released due to herbicide action is mitigated (de Freitas-Silvaet al., 2017).
- Physiological Balance: Hormones, for instance, maintain osmotic and photosynthetic stability under herbicide stress .
- Target Sensitivity Modulation: Auxin-related hormones, for example, alter receptor sensitivity, thus influencing herbicide potency (Song, 2014).

Altogether, the aforementioned mechanisms demonstrate that plant hormones are the regulators of herbicide action at a very subtle level, thus giving the possibility to have more precise control over plant responses. From an agronomic point of view, it is possible to take advantage of these synergies so as to lower herbicide doses, decrease the environmental impact, and make the crops more resilient (Table 3).

Table 3. Documented Synergistic Interactions Between Plant Hormones and Herbicides

Hormone	Herbicide	Plant Species	Observed Effect
ABA	Bispyribac-sodium (ALS inhibitor)	Rice (*Oryza sativa*)	Reduced leaf chlorosis, increased photosynthesis, higher antioxidant activity
BR (EBL)	Tribenuron-methyl (Sulfonylurea)	Wheat (*Triticum aestivum*)	Higher survival, biomass accumulation, enhanced detox enzyme activity
JA	Paraquat	Soybean (*Glycine max*)	Reduced oxidative damage, increased SOD and APX activity
SA	Glyphosate	*Amaranthus palmeri*	Enhanced herbicide toxicity via disruption of redox homeostasis
Auxin (IAA)	2,4-D	*Arabidopsis thaliana*	Modulated herbicide toxicity depending on dose; GH3 gene upregulation
ABA + BR	Multiple herbicides	Rice, Wheat	Improved crop selectivity, reduced herbicide dose requirements

CASE STUDIES

Experimental and field-based studies offer convincing proof of the synergistic interactions of plant hormones and herbicides. Such case studies exemplify the ways in which the exogenous application of hormones affect the efficacy of herbicides, their selectivity, and the decrease of phytotoxic damage in different crop plants. The effects depend on plant species, developmental stage, herbicide type, and environmental factors, however, the main idea of hormonal modulation is still there: hormones can alter plant metabolism in a way that defense activation and growth regulation get balanced during herbicide stress.

Abscisic Acid Pretreatment Enhances Tolerance to ALS-Inhibiting Herbicides in Rice

Abscisic acid (ABA) is a major player in the enhancement of plant tolerance to various abiotic stresses and rice (*Oryza sativa*) studies have demonstrated similar effects for herbicide injury to oxidative stress . Pre-treatment with ABA notably alleviated rice injury caused by bispyribac-sodium, an acetolactate synthase (ALS) inhibitor.

Plants treated with 50 μM ABA for an hour before herbicide exposure visually exhibited fewer symptoms of leaf chlorosis and lower lipid peroxidation than those without ABA treatment. Accordingly, physiological data confirmed that the ABA-treated plants kept higher photosynthetic rates, stomatal conductance, and antioxidant enzyme activities (SOD, CAT, and APX). At the same time, molecular investigations showed elevated expression of *NCED3* (involved in ABA biosynthesis) and *GSTU4* (glutathione transferase), thus pointing to detoxification and stress-protective pathway activation (Sandalio et al., 2023).

Moreover, field experiments documented that a gentle pretreatment with ABA not only lessened herbicide injury symptoms in rice but also increased weed management efficiency due to the maintenance of crop vigor, thus, the crop's competitive power, was improved (Silva et al., 2009). Such a synergistic response is a clear demonstration that ABA integration in herbicide management strategies can be used for selectivity increment without a reduction in the herbicidal potency.

Brassinosteroid-Induced Tolerance to Sulfonylurea Herbicides in Wheat

Among the major stressors of plants, herbicides may result in crop yield losses. To overcome this, Brassinosteroids (BRs) especially 24-epibrassinolide (EBL) which are one of the most potent phytosterols, were found to significantly alleviate the herbicide-induced stress in the research. In the case of wheat (*Triticum aestivum*), the pre-exposure to EBL (0.1 μM) led the plants to become more resistant to tribenuron-methyl, a sulfonylurea herbicide (Manghwar et al., 2022). The plants that got the EBL treatment before the herbicide showed a much greater chance of survival and a lot more fresh weight production as compared to the ones that were only given the herbicide.

The biochemical argument for this goes to the involvement of the BZR1-mediated signaling cascade with the detoxification enzymes (*CYP81A6*, *GSTU19*) transcript and antioxidant enzymes (SOD, CAT) activity that was highlighted by the study (Nakashita et al., 2003). In addition, the BR treatment enhanced the ability of the chlorophyll fluorescence (Fv/Fm ratio) as well as lowered the mda content, hence, signifying less lipid peroxidation, i.e., less oxidative stress, in the leaf tissue (Nakashita et al., 2003).

What is more, this effect was for the most part single: the same field trial's weeds didn't receive similar help, which pointed out the species-related differences in BR signaling. The article also asserted that the injection of BRs lessened the need for the herbicide amounts by up to 25% while at the same time the control of the weed was not deteriorated (Manghwar et al., 2022). These discoveries point to the importance that BRs have as an herbicide synergist that is friendly to the environment and can be applied in cereals.

Auxin Interactions with Synthetic Auxin Herbicides

Research on auxin–herbicide interactions which has been a major concern of both weed controlling and crop tolerating strategies reached its climax in the case of *Arabidopsis thaliana* and maize (Song, 2014). Pre-application of very small amounts of indole-3-acetic acid (IAA) in both these plants led to 2,4-D phytotoxicity modification. In the case when sublethal doses are supplied IAA induces expression of *GH3* genes which encode IAA-amido synthetases i.e., the enzymes that are responsible for the conjugation process of excess auxins or auxin-like herbicides with amino acids thus the level of free hormone lowers.

This biochemical feedback loop limits the unrestrained growth resulting from synthetic auxin herbicides and also limits the necrosis of tissues. On the other hand, if IAA and herbicide are applied simultaneously or if IAA is at a higher concentration, then the cell wall plasticity is affected in such a way that herbicides are taken up more rapidly and the toxicity thus increases in susceptible weeds (Neve et al., 2024). Therefore, the existence of a concentration-dependent mode that determines the potential for antagonism or synergy between IAA and 2,4-D is shown by the maintenance of hormonal homeostasis.

Jasmonic Acid Mitigates Paraquat Toxicity in Soybean

Paraquat is a non-selective, quick-acting herbicide that is known to create reactive oxygen species (ROS) that leads to peroxidation of the membrane and damage to chloroplasts. Soaking leaves in exogenous jasmonic acid (JA) solution has been reported to ease the paraquat-induced oxidative stress in soybean (Glycine max) (Sandalio et al., 2023).

After paraquat treatment, plants pretreated with 100 μM methyl jasmonate (MeJA) showed less electrolyte leakage and MDA content. The levels of antioxidant enzymes such as superoxide dismutase (SOD) and ascorbate peroxidase (APX) were increased, which is consistent with JA-mediated activation of ROS detoxification pathways. A transcriptome profiling analysis revealed that MeJA pretreatment led to the expression of genes related to phenylpropanoid metabolism that not only helps in structural support of the cell wall but also in ROS scavenging (Silva et al., 2009).

This interaction between JA and paraquat serves as an example of how hormones can alter defense metabolism to lessen herbicide injury, thus giving a chance to increase crop resilience during post-emergence weed control.

Salicylic Acid Potentiates Glyphosate Efficacy in Weeds

Salicylic acid (SA) alters the behavior of both crops and weeds to glyphosate, a non-selective herbicide that is the most commonly used. Pretreatment with SA (0.5 mM) in *Amaranthus palmeri* and *Chenopodium album* led to greater glyphosate toxicity, causing more inhibition of the shikimate pathway enzymes and shikimic acid accumulation (Vivancos et al., 2011). The main reason for the response was considered to be the disruption of antioxidant homeostasis by SA and that the EPSPS enzyme recovery process was affected.

On the other hand, in soybean and maize, SA pretreatment is a protective measure against glyphosate toxicity as it leads to the activation of antioxidant systems and the facilitation of glutathione-dependent detoxification (de Freitas-Silva et al., 2017). Consequently, SA may enhance or inhibit the effect of glyphosate, depending on the plant species and redox status.

These contradictory responses to the hormone-herbicide interaction point out that the relationship is very complicated and, therefore, it is very important to consider the species when taking such interactions into account for practical agricultural applications.

Integration in Field and Agronomic

Controlled experiments on hormone–herbicide combinations revealed their benefits, which were also realized through the applications of these combinations in the field. In the rice and maize systems, treatments with ABA and BR not only resulted in the improvement of crop selectivity but also resistance to high herbicide pressure (Silva et al., 2009). In the same manner, in wheat and soybean, the application of JA and SA alleviated the symptoms of oxidative stress and accelerated the recovery rates after herbicide exposure (Sandalio et al., 2023).

These synergistic interventions have an economic advantage of herbicide input reduction by 15–30%, which leads to lower production costs and at the same time, reduction of environmental residues (Neve et al., 2024). From an ecological point of view, the use of hormonal treatments in herbicide programs is a step towards sustainable weed management as it helps in the reduction of chemical overuse and strengthening of plant physiological resilience.

HORMONAL REGULATION OF HERBICIDE METABOLISM AND RESISTANCE

Herbicide metabolism and resistance regulation in plants by different mechanisms mainly includes detoxification enzymes, signaling cascades, and hormonal control systems; this is a rather complicated issue. The plant hormones: abscisic acid (ABA), jasmonic acid (JA), salicylic acid (SA), brassinosteroids (BRs), and auxins-are the major characters that modulate the detoxification machinery, thus, influencing both herbicide tolerance as well as resistance evolution. Understanding the role of hormones in metabolic resistance is a very vital aspect when integrated weed management strategies are being planned which eventually leads to fewer herbicide-resistant populations.

Phases of Herbicide Metabolism and Hormonal Influence

Herbicide metabolism in plants is majorly categorized into four phases (Cummins et al., 2009):

- Phase I – Functionalization: The herbicide molecule is altered via one of the three processes: oxidation, reduction, or hydrolysis. These are mostly done by cytochrome P450 monooxygenases (CYP450s).
- Phase II – Conjugation: The compounds resulting from Phase I are conjugated with one of the following: glutathione, glucose, or amino acids by the action of transferases (GSTs, UGTs).
- Phase III – Compartmentalization: The transport of the conjugated herbicides into vacuoles or cell walls is done by ATP-binding cassette (ABC) transporters.
- Phase IV – Degradation: Eventually, this is the last step that sees the breaking down of the matter to yield the nontoxic metabolites that may be stored or excreted.

Plant hormones are capable of governing transcriptional and post-translational changes in each of these phases. For example, under xenobiotic stress, both the abscisic acid (ABA) and the jasmonic acid (JA) are reported to promote the transcription of the cytochrome P450 (CYP450) and glutathione S-transferase (GST) genes (Sandalio et al., 2023). Whereas brassiosteroids (BRs) and salicylic acid (SA) influence the transporter activity as well as the secondary metabolism that is involved in either detoxification or sequestration of the herbicide (Silva et al., 2009).

Abscisic Acid and Cytochrome P450 Activation

Under the influence of herbicide stress, trans-factors tandemly operated by ABA such as *ABF2* and *AREB1* not only energize promoters of *CYP81A6* and *CYP72A31* i.e. two major oxidizing P450 herbicide genes but also help in quicking the detoxification process and lessening the damages to the cells by the herbicide as a result of gene up-regulation (Riechers et al., 2010).

For instance, a moderate dose of artificially-instigated ABA in rice and wheat made the plants more resistant against the symbiotic inhibition of ALS herbicides by the gradual up-regulation of the genes mentioned above and, thus, faster drug metabolism and the lessening of cellular injuries ensued .

Mechanism is however double-sided. It heavily relies on the existence of metabolic resistance in weeds. Just as the magnified enzyme activities lead to elevated resistance phenomenon in these grasses, the overexpression of ABC transporters, where alongside the CYP450s, the raised embolism is called, as shown in result of Pan et al., studies, is the main reason that rebellion against multiform herbicides in case of the varied weed materials sources ith Echinocloa crus-galli (barnyard grass), (Pan et al., 2021). Hence, while ABA contributes to crop tolerance enhancement, the upregulation in the weed side may facilitate resistance evolution.

Jasmonic Acid and Glutathione S-Transferase (GST) Induction

Jasmonates are pivotal for the regulation of detoxification of stress-induced agents, most notably, they achieve this through the stimulation of glutathione S-transferases (GSTs). Activated genes GSTU and GSTF, which are responsive to JA, have MeJA treatment leading to their transcriptional activation which is mediated by promoter (Li et al., 2022).

In soybean and maize, the JA pretreatment led to the enhancement of GST activity and to the alleviation of paraquat toxicity through the promotion of ROS scavenging and the creation of conjugates with toxic radicals (Sandalio et al., 2023). Correspondingly, in Lolium rigidum resistant biotypes, the rise of basal JA levels together with the continuous expression of GST, thus non-target-site resistance (NTSR) to ACCase and ALS inhibitors, has been postulated as a possible mechanism (Délye, 2013).

The interconnection of JA signaling with GST induction serves as an example of a mechanism with double-edges: the protective side against crop oxidative herbicide injury, while the other side can be strengthened by weed resistance through efficient detoxification promotion.

Brassinosteroids and Multidrug Transporter Regulation

Brassinosteroids modulate herbicide metabolism not only by enhancing antioxidant defenses but also by activating membrane transport systems responsible for xenobiotic efflux. Studies in wheat and maize revealed that 24-epibrassinolide (EBL) application upregulated ABC transporter genes (*ABCG36, ABCB19*) and multidrug and toxic compound extrusion (MATE) transporters (Manghwar et al., 2022).

These transporters are the main players in Phase III metabolism, where they expel conjugated herbicide metabolites from the cytosol thus, vacuoles or apoplasts, are where they belong. The efflux that is enhanced leads to less intracellular herbicide concentration and, therefore, less toxicity. The same goes for the overexpression of similar transporters as found in *Amaranthus retroflexus* and most likely also regulated by BR-like signaling that, as a result, abet cross-resistance to various herbicide chemistries (Délye, 2013).

Such factual proof puts BRs in the double role of being crop health defenders and, also, probable metabolic resistance facilitators, depending, however, on species and expression pattern.

Salicylic Acid and Redox-Dependent Detoxification

Salicylic acid (SA) is a key player in the redox changes that occur in the cell as a result of herbicide treatment and that eventually lead to detoxification and resistance. Thus, in glyphosate-treated soybean, SA pretreatment led the plant to enhance the expression of antioxidant enzymes (SOD, CAT, APX) and to increase the reduced glutathione (GSH) content

(de Freitas-Silva et al., 2017). GSH is a substance that is conjugated to herbicides via enzyme GST, thus providing a direct link of SA signaling to herbicide metabolism.

It is worth noting that, in *Chenopodium album* and *Amaranthus palmeri*, the spiking of SA after glyphosate treatment was the cause of the redox imbalance, which in turn led to increased herbicide susceptibility (Vivancos et al., 2011; Kaya Altop et al., 2025). The contradictory effects highlight that SA serves as a modulator that changes its role depending on the cellular redox buffering capacity and metabolic fluxes and whose impact is therefore redox-dependent.

Hormonal Crosstalk and Non-Target-Site Resistance (NTSR)

Non-target-site resistance (NTSR) is a condition where plants are resistant to herbicides but the cause is not a mutation at the target site. Instead, it results from overproduction of detoxification, sequestration, or reduced translocation. Hormonal crosstalk—especially that involving ABA, JA, and BR pathways—has been suggested to regulate NTSR mechanisms (Délye, 2013; Pan et al., 2021).

One of the examples is the combined effect of the ABA-induced P450 expression with the JA-mediated GST activation and BR-driven transporter upregulation that generates a strong metabolic shield against herbicides. In the transcriptome of resistant *Echinochloa* and *Alopecurus* species, the authors found that genes related to hormone signaling were not only present in high numbers but also co-expressed with detoxification enzymes (Pan et al., 2021). The authors of the paper came to the conclusion that NTSR is not solely a biochemical phenomenon, but rather an adaptive, physiologically controlled by hormones one.

Implications for Weed Management

Knowing how hormones control herbicide metabolism can be very instrumental in the fight against resistance. Hormonal treatments from outside can, thus, be a means of crops' tolerance enhancement and of the cutting down of chemical inputs. Meanwhile, in the case of weeds, a strike at hormone-regulated detoxification pathways may be a way to get herbicide effectiveness back.

On the other hand, a cortisone biosynthesis or signaling roadblock may turn the metabolic resistance off in bad-for-the-ecosystem-weeds, and thus make their populations susceptible again. At the same time, small amounts of BR or JA might be used for crop selectivity purposes. Taking advantage of such hormonal insights in herbicide design and management might pave the way for the next-generation synergistic formulations that put resistance risks at the lowest while boosting performance to the highest (Figure 1).

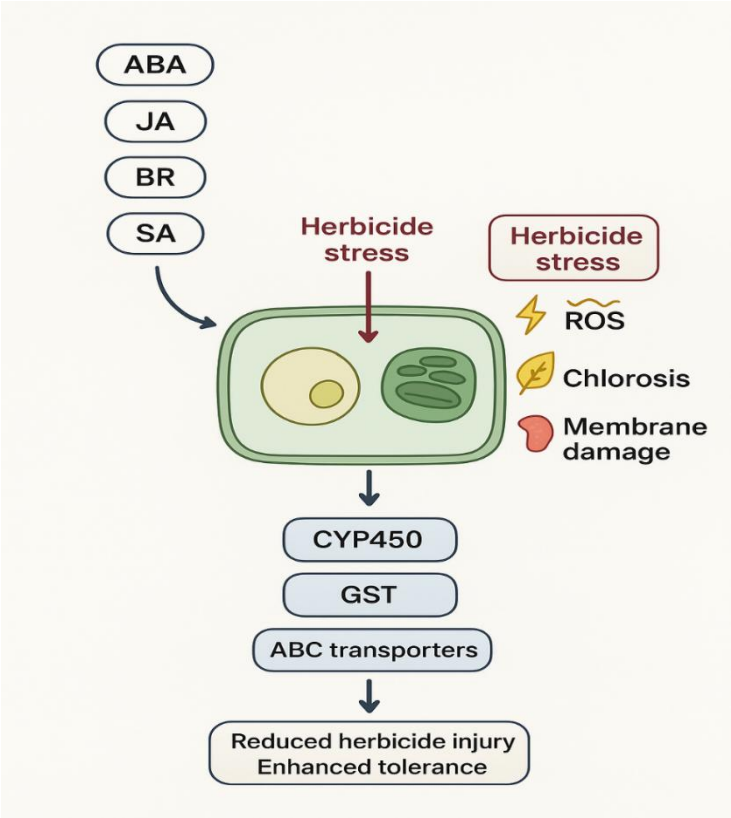


Figure 1. Antioxidant responses and stress tolerance

FUTURE PERSPECTIVES AND APPLICATIONS

Understanding how one plant hormone supports or interferes with an herbicide action unveils a whole new world of possibilities for weed control that is both environment and crop-friendly. As world farming is heading towards less use of chemicals and becoming more climate-resilient, combining hormone-based strategies with herbicide uses is a nice way to keep the effect and lower the risk to nature. Next research can take the lead by uncovering the mechanisms, providing the models, and inventing biotechnological on these synergies.

Integrating Hormonal Modulators into Weed Management Programs

The idea of employing external hormones or hormone-mimics as herbicide synergists has significantly propelled the potentials of improving the selectivity of the crops and diminishing the amount of chemicals used. Yet, its actualization in real life is heavily dependent on the knowledge of dose–response relations, the right time for the application, and the stability of the environment.

Field experiments have confirmed that the cereal pretreatment with ABA or brassinosteroids could raise their resistance to ALS inhibitors and sulfonylureas, thus allowing herbicide doses to be lowered without the quality of weed control being weakened (Manghwar et al., 2022; Silva et al., 2009). In like manner, jasmonic acid and salicylic acid application have proved their effectiveness in alleviating oxidative stress brought about by paraquat or glyphosate (Sandalio et al., 2023).

The next step is that of commercial formulation where hormones or their analogs can be concurrently applied with herbicides as *safener–synergist* blends. Such compositions may attain the desired physiological modulation thereby enabling selective detoxification of crops while weeds remain unaffected.

The extent to which such an endeavor will be successful may hinge on our grasp of the specificity in cross-species signaling as well as the metabolic fate of supplemented hormones in the open-air environment.

Biotechnological Approaches: Engineering Hormonal Pathways

Biotechnology presents possibilities to alter hormonal signaling that can result in better herbicide tolerance and increased metabolic efficiency. One may resort to genetic engineering and genome editing (e.g., CRISPR/Cas9) to achieve the desired changes in the production/supply or response of hormones. To cite an example, the upregulation of *BZR1* (brassinosteroid signaling), *NCED3* (ABA biosynthesis), or *GSTU19* (JA-responsive detoxification) in transgenic plants might be a way to provide the latter with the capability of withstanding herbicide-induced oxidative stress (Pan et al., 2021).

Besides that, some recent works have led to the idea of coming up with artificial transcriptional regulators that resemble hormone response elements and thus selectively turn on detoxification genes when herbicide stress is detected (Riechers et al., 2010). Such mechanisms can make plants "aware" of herbicide presence and thus trigger the metabolic pathways of protection without the need for constant hormonal intervention.

However, the authors of the article recommend taking into account the possible ecological implications, regulatory issues, and problems related to consumer acceptance when considering these pros and cons. Any future genetic modifications should be carried out with maximum precision and minimum unintended effects, thus not giving rise to the problem of resistance evolution in weeds.

Hormone–Herbicide Crosstalk in Climate-Resilient Agriculture

Climatic changes bring about extreme weather events most of the time. Drought, heat, and salting that affect the herbicide's activity and the hormone signaling are the trio that goes a step further. To illustrate, a plant when it is under drought stress, it makes more ABA by itself. Hence, the changed uptake and metabolism of a herbicide may be the result of the cellular signaling . As if that were not enough, the changes in oxygen levels in the atmosphere and temperature also have an impact on the redox balance thus causing a change in the performance of the reactive oxygen species (ROS)-mediated herbicides like paraquat (Song, 2014).

In such a case, optimizing hormone-based herbicides would be among the ways to attain climate-resilient weed management. For instance, not only by helping the plant to maintain photosynthesis but also by initiating antioxidant defense, ABA and brassinosteroids might behave as a verythin protective layer for plants that are subjected to both herbicide and abiotic stresses. Foreseeing the interlink between abiotic stress effects and herbicide response will be a major factor in coming up with flexible management strategies that are prepared for the ever-changing environment.

Systems Biology and Predictive Modeling

The future investigations cannot be stuck on separate or isolated events but rather should aim at a holistic, system-level understanding of the interaction of hormones and herbicides. By merging transcriptomics, metabolomics data, and machine learning models, scientists can determine the interaction if it is synergistic or antagonistic by the presence of molecular signatures (Pan et al., 2021).

Besides, computational models can also recognize the main regulatory hubs e.g. transcription factors, kinases, or transporters that control the decision of a hormonal signal to increase or decrease herbicide toxicity. The large multi-omics data sets from both crops and weeds will

help researchers in uncovering common and different pathways, thus the coming up of species-specific management strategies will be less time-consuming and more accurate.

Afterward, machine learning techniques may be employed to generate in silico hormone–herbicide combinations thus not only regulating field efficiency but also predicting resistance evolution risks.

Sustainable and Regulatory Implications

The implementation of hormonal control together with herbicide management is a step forward towards achieving the set of global targets for the sustainable intensification of agriculture. The hormone–herbicide synergy can result in the use of less chemicals, fewer environmental pollutants, and crop resilience, which are the essential elements of the European Green Deal and other sustainability frameworks worldwide (FAO, 2021).

Nevertheless, the legal measures surrounding this matter have to be changed accordingly to be able to cope with this new paradigm. At present, hormones and growth regulators fall under a grey area between fertilizers and pesticides and thus require new evaluation criteria for co-formulated products. In addition to that, it would be necessary to conduct long-term ecological studies to find out potential NTEs, e.g. the effects on soil microbiota and organisms that are beneficial to humans.

Thinking from the side of the economy, the development of synergistic hormone–herbicide formulations could be a good thing as far as the input costs are concerned; they would be lower for farmers; while at the same time, productivity and environmental safety would be at a high level. This method, which is fully in line with the principles of agronomic efficiency and ecological stewardship, may be considered the foundation of the next generation of crop management.

CONCLUCIONS

The interrelationship of plant hormones and herbicides is a prime example of a complex biochemical conversation going on in plants - a very delicate balancing of development regulation, defense mechanisms, and detoxification processes. By utilizing this innate harmony, we can revolutionize the future of weed control from the current heavy chemical dependence toward mainly biochemical-based control, integrating hormonal manipulation with precision agriculture and biotechnology. Collaboration among plant physiologists, weed scientists, molecular biologists, and agronomists should not be interrupted if we want to make these scientific findings real and practical on a large scale. At the end of the day, hormone-assisted herbicide management is not just about doing the tweaking; it's a huge step towards a smarter, more flexible, and sustainable system of crop protection.

REFERENCES

Abeles, F. B., Morgan, P. W., & Saltveit, M. E. (1992). *Ethylene in plant biology* (2nd ed.). Academic Press.

Clouse, S. D., & Sasse, J. M. (1998). Brassinosteroids: Essential regulators of plant growth and development. *Annual Review of Plant Physiology and Plant Molecular Biology, 49,* 427–451.

Cummins, I., Bryant, D. N., Edwards, R. (2009). Safener responsiveness and multiple herbicide resistance in the weed black-grass (*Alopecurus myosuroides*). *Plant Biotechnology Journal, 11*(3), 256–265.

Cutler, S. R., Rodriguez, P. L., Finkelstein, R. R., & Abrams, S. R. (2010). Abscisic acid: Emergence of a core signaling network. *Annual Review of Plant Biology, 61*, 651–679.
Davies, P. J. (2010). *Plant hormones: Biosynthesis, signal transduction, action!* Springer.
Dayan, F. E., & Duke, S. O. (2014). Natural compounds as next-generation herbicides. *Plant Physiology, 166*(3), 1090–1105.
de Freitas-Silva, L., Rodríguez-Ruiz, M., Houmani, H., da Silva, L. C., Palma, J. M., & Corpas, F. J. (2017). Glyphosate-induced oxidative stress in Arabidopsis thaliana affecting peroxisomal metabolism and triggers activity in the oxidative phase of the pentose phosphate pathway (OxPPP) involved in NADPH generation. *Journal of plant physiology, 218*, 196–205.
Délye, C. (2013). Unravelling the genetic bases of non-target-site-based resistance (NTSR) to herbicides: a major challenge for weed science in the forthcoming decade. *Pest Management Science, 69*(2), 176–187.
Depuydt, S., & Hardtke, C. S. (2011). Hormone signaling crosstalk in plant growth regulation. *Current Biology, 21*(9), R365–R373.
Duke, S. O. (2012). Why have no new herbicide modes of action appeared in recent years? *Pest Management Science, 68*(4), 505–512.
Duke, S. O., & Powles, S. B. (2008). Glyphosate: A once-in-a-century herbicide. *Pest Management Science, 64*(4), 319–325.
FAO. (2021). *The state of the world's land and water resources for food and agriculture: Systems at breaking point*. Food and Agriculture Organization of the United Nations.
Goldberg-Cavalleri, Alina & Onkokesung, Nawaporn & Franco Ortega, Sara & Edwards, Robert. (2023). ABC transporters linked to multiple herbicide resistance in blackgrass (Alopecurus myosuroides). Frontiers in Plant Science. 14. 1082761. 10.3389/fpls.2023.1082761.
Grossmann, K. (2010). Auxin herbicides: Current status of mechanism and mode of action. *Pest Management Science, 66*(2), 113–120.
Grossmann, K., & Kwiatkowski, J. (1999). Regulation of phytohormone levels, leaf senescence and stress resistance by herbicidal inhibitors of amino acid biosynthesis. *Pesticide Science, 39*(3), 263–273.
Heap, I. (2023). The international survey of herbicide resistant weeds. *WeedScience.org*. Retrieved from http://www.weedscience.org
HRAC. (2023). *Herbicide mode of action classification.* Herbicide Resistance Action Committee. https://hracglobal.com
Kaya Altop, E., Jabran, K., Pala, F., & Mennan, H., (2025). Multiple resistance to EPSPS and ALS inhibitors in Palmer amaranth (*Amaranthus palmeri*) identified in Turkey. Weed Research , vol.65, no.1.
Kieber, J. J., & Schaller, G. E. (2018). Cytokinin signaling in plant development. *Development, 145*(4), dev149344.
Leyser, O. (2018). Auxin signaling. *Plant Physiology, 176*(1), 465–479.
Li, Cong & Xu, Mengxi & Cai, Xiang & Han, Zhigang & Si, Jinping & Chen, Donghong. (2022). Jasmonate Signaling Pathway Modulates Plant Defense, Growth, and Their Trade-Offs. International Journal of Molecular Sciences. 23. 3945. 10.3390/ijms23073945.
Manghwar, H., Hussain, A., Ali, Q., & Liu, F. (2022). Brassinosteroids (BRs) Role in Plant Development and Coping with Different Stresses. *International journal of molecular sciences, 23*(3), 1012.
Mittler, R. (2017). ROS are good. *Trends in Plant Science, 22*(1), 11–19.
Morgan, P. W., & Drew, M. C. (1997). Ethylene and plant responses to stress. *Physiologia Plantarum, 100*(3), 620–630.

Nakashita, H., Yasuda, M., Nitta, T., Asami, T., & Yoshida, S. (2003). Brassinosteroid functions in a broad range of disease resistance in tobacco and rice. *Plant Journal, 33*(5), 887–898.
Neve, P., Matzrafi, M., Ulber, L., Baraibar, B., Beffa, R., Belvaux, X. et al. (2024) Current and future glyphosate use in European agriculture. *Weed Research*, 64(3), 181–196.
Opdenakker, K., Remans, T., Keunen, E., Vangronsveld, J., & Cuypers, A. (2012). Exposure of *Arabidopsis thaliana* to Cd or Cu triggers a stress response with altered MAPK signaling and expression of hormonal pathways. *Environmental and Experimental Botany, 83*, 33–41.
Pan, L, Guo Q, Wang J, Shi L, Yang X, Zhou Y, Yu Q, Bai L. (2022). CYP81A68 confers metabolic resistance to ALS and ACCase-inhibiting herbicides and its epigenetic regulation in Echinochloa crus-galli. Journal of Hazardous Materials 428:128225
Riechers, D. E., Kreuz, K., & Zhang, Q. (2010). Detoxification without intoxication: herbicide safeners activate plant defense gene expression. *Plant Physiology, 153*(1), 3–13.
Sandalio, L. M., Espinosa, J., Shabala, S., León, J., & Romero-Puertas, M. C. (2023). Reactive oxygen species- and nitric oxide-dependent regulation of ion and metal homeostasis in plants. *Journal of experimental botany*, *74*(19), 5970–5988.
Santner, A., & Estelle, M. (2009). Recent advances and emerging trends in plant hormone signaling. *Nature, 459*(7250), 1071–1078.
Silva, C., Gomes, M., & Freitas, S. (2009). Effects of herbicides, associated to a brassinosteroid Analogue, on the photosynthetic apparatus of Eucalyptus grandis seedlings. Planta daninha, 27(4), 789-797.
Song, Y. (2014). Insight into the mode of action of 2,4-Dichlorophenoxyacetic acid (2,4-D) as an herbicide. *Journal of Integrative Plant Biology, 56*(2), 106–113.
Velini, E. D., Alves, E., Godoy, M. C., Meschede, D. K., Souza, R. T., & Duke, S. O. (2008). Glyphosate applied at low doses can stimulate plant growth and endogenous hormone production. *Pest Management Science, 66*(5), 488–494.
Vivancos, P. D., Driscoll, S. P., Bulman, C. A., Ying, L., Emami, K., Treumann, A., ... & Foyer, C. H. (2011). Perturbations of amino acid metabolism associated with glyphosate-dependent inhibition of shikimic acid metabolism affect redox homeostasis. *Plant Physiology, 157*(1), 256–268.
Wasternack, C., & Hause, B. (2013). Jasmonates: Biosynthesis, perception, signal transduction and action in plant stress response, growth and development. *An Update to the 2007 Review in Annals of Botany, 111*(6), 1021–1058
Woodward, A. W., & Bartel, B. (2005). Auxin: Regulation, action, and interaction. *Annals of Botany, 95*(5), 707–735.
Yamaguchi, S. (2008). Gibberellin metabolism and its regulation. *Annual Review of Plant Biology, 59*, 225–251.
Yu, Q., & Powles, S. B. (2014). Metabolism-based herbicide resistance and cross-resistance in crop weeds: A threat to herbicide sustainability and global crop production. *Plant Physiology, 166*(3), 1106–1118.

METAGENOMIC APPROACHES TO EXPLORE WEED-ASSOCIATED MICROBIOMES

Assoc. Prof. Dr. Emine KAYA ALTOP

Ondokuz Mayıs University, Faculty of Agriculture, Department of Plant Protection, Samsun, Turkiye

ORCID ID: https://orcid.org/0000-0002-0987-9352

Ph.D. Sine KAYA

Ondokuz Mayıs University, Graduate School of Natural and Applied Sciences, Department of Plant Protection, Samsun, Turkiye

ORCID ID: https://orcid.org/0000-0002-4219-9148

ABSTRACT

Weeds exacerbate the loss of agricultural productivity disproportionately to other plant groups because of their rapid growth, high adaptability, and the fact that they possess the traits for competition. Various traditional methods of chemical controls have caused herbicide resistance to develop and have resulted in environmental problems. The microbiome of weeds means the community of bacteria, fungi, and archaea living in the rhizosphere, phyllosphere, and endosphere. These microbes are involved in nutrient acquisition, stress resistance, release of chemicals that affect other organisms, and adaptation to herbicide use. Progress in metagenomic techniques such as amplicon sequencing, shotgun metagenomics, functional metagenomics, and bioinformatics analyses has empowered to uncover the exhaustive profile of these microbial communities.The knowledge of their diversity, composition, and functional roles paves the way for the implementation of a sustainable management system of weeds by such means as microbial bioherbicides, inoculants, and their combination with precision agriculture. Although there are difficulties arising from field variability, host specificity, and regulatory obstacles, the research that will use multi-omics approaches combined with long-term field studies, will be able to provide a solution to the problem of weed control at no harm to the environment and at a low cos

Keywords: Weed microbiome, Metagenomics, Bioherbicides, Functional metagenomics, Sustainable agriculture, Microbial diversity

INTRODUCTION

Weeds threaten agricultural productivity recurrently, due to their traits of high adaptability, rapid growth, and competitiveness (Oerke, 2006). The use of chemicals as a control means has caused the development of herbicide resistance that is spreading like wildfire thereby contaminating the environment and causing various negative impacts on the organisms that are not targets of the chemicals used (Duke, 2011). In the situation of the weed microbiome, which is the microbial communities associated with weeds, the understanding of the problem offers the novel insights into biology, adaptation, and biocontrol of the weed (Santoyo et al., 2016).

Microorganisms that are found in the rhizosphere, phyllosphere, or endosphere of weeds can have a profound impact on plant growth, nutrient uptake, and tolerance to stress, thus they can regulate the competitive ability of plants. Besides, these communities are an almost unlimited reservoir of bioherbicides or products that promote plant growth (Bulgarelli et al., 2013; Berg & Raaijmakers, 2018). Moreover, weed-associated microbiomes can influence the interaction of different plants with each other so as to either lessen or intensify the competition of the weed.

This article serves to (1) review the metagenomic tools and methods for investigating the microbiomes associated with weeds, (2) consider the composition, diversity, and functional groups of such microbial communities, (3) leverage their capabilities for ecologically sound weed control, and (4) point to the next avenues of research in the field of weed metagenomics and biocontrol.

METAGENOMIC TOOLS AND METHODOLOGIES

Metagenomics allow the study of microbial communities without culture limitations and thus cover microbial diversity,

DNA Extraction and Sample Preparation: Materials may be obtained from the soil of the rhizosphere, the root endosphere, the phyllosphere, and seeds (Turner et al., 2013). DNA extraction techniques are designed to reduce the contamination of DNA from the host while increasing bacterial, fungal, and archaeal DNA recovery. Generally, the MoBio PowerSoil and Qiagen DNeasy are popular kits for the destructive process of diverse microorganisms if they are usually combined with bead-beating (Niu et al., 2017).

Sequencing Approaches: Amplicon sequencing is focused on marker genes—16S rRNA for bacteria and ITS for fungi—used to describe taxonomic diversity. In addition to being low-priced and high-throughput, the technique is limited to already existing reference sequences (Caporaso et al., 2010). In shotgun metagenomics, the sequencing is done for the whole DNA. This gives room for both taxonomic and functional profiling besides the discovery of new genes, pathways for secondary metabolites, and gene clusters for herbicide- or allelochemical-related products (Quince et al., 2017). Metatranscriptomics studies RNA to figure out the functions of microbes that are active in a certain environment or under given conditions of the host (Carvalhais et al., 2015).

Bioinformatics Analysis: FastQC and Trimmomatic are the tools used for quality control in data processing. Taxonomic classification of amplicon data can be achieved with QIIME2, Mothur, or Kraken2 whereas shotgun reads can be aligned with the NCBI, SILVA, or UNITE databases. Functional annotation with KEGG, COG, or eggNOG may result in the identification of microbial functions and can also be used for the identification of microbial functions in the rhizosphere such as the production of allelochemicals and stress tolerance mechanisms (Louca et al., 2016).

Functional Metagenomics: Functional metagenomics requires the use of a vector to which cloned environmental DNA is attached for screening the presence of bioactive compounds, among which are herbicidal metabolites. This approach enables the discovery of enzymes or secondary metabolites with potential applications in weed suppression or crop protection (Handelsman, 2004).

Statistical and Network Analysis: Changes in microbial diversity and community composition are being assessed through the use of alpha- and beta-diversity metrics (Shannon and Simpson indices). Co-occurrence networks disclose microbial interactions, keystone taxa,

as well as the potential growth-promoting or weed-suppressive microbes (Faust & Raes, 2012) (Figure 1, Table 1).

Table 1. Metagenomic Approaches and Applications in Weed Microbiome Research

Approach	**Purpose**	**Advantages**	**Limitations**
Amplicon sequencing	Taxonomic profiling	Cost-effective, high-throughput	Limited to known sequences
Shotgun metagenomics	Functional and taxonomic profiling	Detects novel genes and pathways	Requires high computational resources
Metatranscriptomics	Active microbial functions	Captures functional activity	RNA degradation issues, complex analysis
Functional metagenomics	Discovery of bioactive compounds	Identifies herbicidal metabolites	Labor-intensive, requires cloning systems

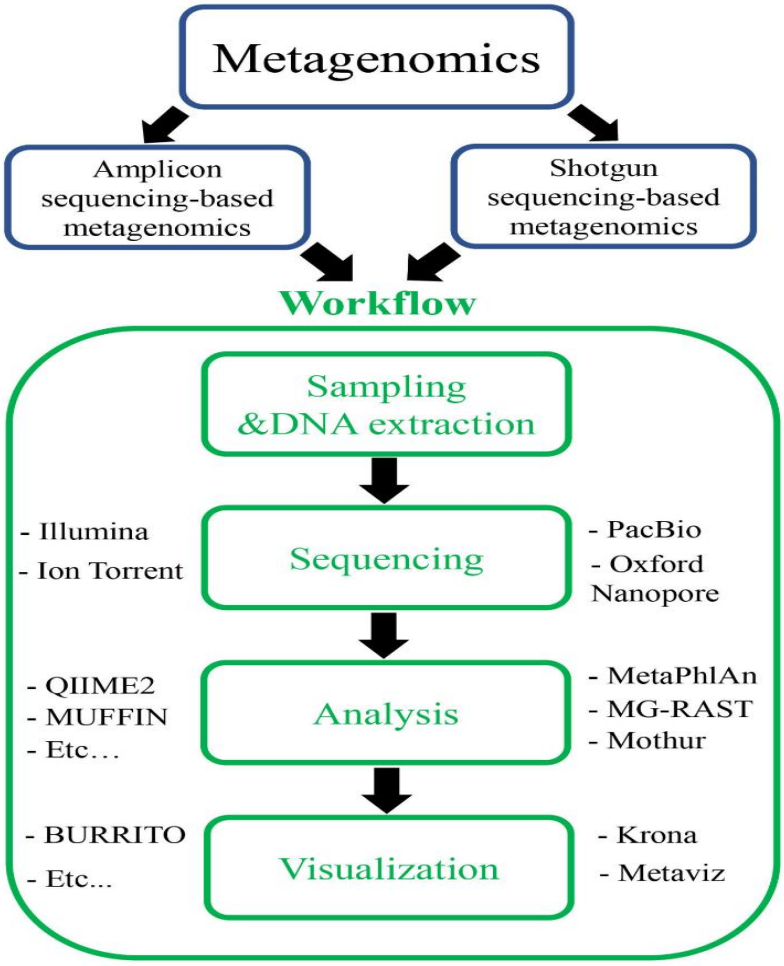


Figure1. Metagenomic tools and methodologies

DIVERSITY AND COMPOSITION OF WEED-ASSOCIATED MICROBIOMES

Weed-associated microbiomes are the complex communities inhabiting the rhizosphere, endosphere, phyllosphere, and seeds. A thorough understanding of their diversity reveals the mechanisms of weed adaptation, stress tolerance, and allelopathic potential (Bulgarelli et al., 2013). Metagenomic approaches allow profiling of both culturable and unculturable taxa.

Bacterial Diversity: Basically, the bacterial communities of the rhizosphere are largely dependent on Proteobacteria, Actinobacteria, Bacteroidetes, and Firmicutes (Turner et al., 2013). For instance, the *Echinochloa crus-galli* rhizosphere is the region where plant growth-promoting *Bacillus* species that facilitate nutrient acquisition are isolated (Niu et al., 2017). Endophytic bacteria which colonize roots and shoots, and by that modulate hormone signaling and stress tolerance; *Pseudomonas fluorescens* is a typical example of such bacteria which produces siderophores and IAA, thus, affecting weed competitiveness (Santoyo et al., 2016) (Table 2).

Table 2. Major Bacterial Taxa in Weed Rhizosphere and Endosphere

Taxa	Habitat	Functional Role	Example Weed
Proteobacteria	Rhizosphere	Nitrogen fixation, nutrient cycling	*Echinochloa crus-galli*
Actinobacteria	Rhizosphere/Endosphere	Phosphate solubilization, IAA production	*Amaranthus retroflexus*
Firmicutes	Rhizosphere	Siderophore production, stress tolerance	*Lolium rigidum*
Bacteroidetes	Rhizosphere	Organic matter decomposition	*Chenopodium album*

Fungal Diversity: The fungal consortia, which comprise Ascomycota, Basidiomycota, and Glomeromycota, are the common inhabitants of the rhizosphere and the endosphere (Rodriguez et al., 2009). Besides, they also become the allelochemical producers (Tesio and Ferrero, 2010) and get involved in nutrient uptake through mycorrhizal associations, thus, that indirectly influences the weed-crop competition (Smith & Read, 2008). *Fusarium oxysporum* endophytes in *Amaranthus* spp. are the best examples of the fungi-mediated seedling vigor reduction (Table 3).

Table 3. Major Fungal Taxa in Weed Microbiomes

Taxa	Habitat	Functional Role	Example Weed
Ascomycota	Endosphere	Allelochemical production	*Amaranthus spp.*
Basidiomycota	Rhizosphere	Nutrient cycling	*Echinochloa crus-galli*
Glomeromycota	Rhizosphere	Mycorrhizal nutrient uptake	*Lolium rigidum*
Fusarium spp.	Endosphere	Allelopathic metabolite synthesis	*Amaranthus* spp.

Archaeal Diversity: Even though the study of Archaea is less covered, these organisms play important roles in the process of nitrogen cycling and in improving the fertility of the soil (Prosser, 2012). Among the methanogenic and ammonia-oxidizing archaea, that are found in the soils of *Lolium rigidum*, there is also Thaumarchaeota which can have an effect on nutrient availability and the competitive dynamics.

Microbial Community Structure: Alpha diversity is influenced by different variables such as the species of weed, type of soil, and environmental conditions (Louca et al., 2016). On the

other hand, beta diversity points out the differences in the microbial communities that are found around various types of weeds which is an indication of host-specific recruitment (Bulgarelli et al., 2013). The keystone taxa are those that.

Environmental Influences: Factors that determine microbial communities and consequently affect weed competitiveness and microbiome functionality include soil pH, moisture, organic matter, agronomic practices, seasonal changes, and crop rotation (Turner et al., 2013; Vurukonda et al., 2018).

FUNCTIONAL ROLES OF WEED-ASSOCIATED MICROBIOMES

Microbes associated with weeds are the main contributors to the plant growth, stress tolerance, allelopathy, and herbicide adaptation. Functional metagenomics and multi-omics technological interventions disclose the genes and the pathways that lead to these roles (Berg & Raaijmakers, 2018; Louca et al., 2016).

Nutrient Acquisition: The rhizosphere microbes are the ones that may result in nitrogen fixation (*Rhizobium*, *Azospirillum*), phosphate solubilization (*Bacillus*, *Pseudomonas*), and also iron acquisition through the siderophores (Santoyo et al., 2016). For instance, the *Amaranthus retroflexus* rhizosphere is the place where nutrient availability-promoting *Bacillus subtilis* strains are found (Niu et al., 2017).

Stress Tolerance: The endophytes are the ones which bring resistance to the host against drought, salinity, and temperature extremes through hormonal modulations (IAA, ABA, cytokinins), osmoprotectant productions (proline, trehalose), and ROS scavenging (Vurukonda et al., 2018; Maksimov et al., 2010). For example, drought tolerance capacity in *Echinochloa crus-galli* is enhanced by the *Pseudomonas fluorescens* endophytes through the manipulation of ABA signalling.

Allelopathic Interactions: The microbial metabolites, such as fusaric acid from *Fusarium* or alternariol from *Alternaria*, are energic inhibitors of the growth of the plants surrounding them (Tesio & Ferrero, 2010). Functional metagenomics assist in pinpointing the gene clusters that code for these metabolites, thus, facilitating the development of bioherbicides (Handelsman, 2004).

Herbicide Resistance and Degradation: Some microorganisms that live in collaboration with the weeds can detoxify herbicides, hence, they are the ones who play a leading role in resistance development. The genes responsible for the production of herbicide-degrading enzymes in the rhizosphere of weeds have been revealed through shotgun metagenomics (Duke, 2011; Teske et al., 2013).

Microbial Interactions and Community Synergy: These are the synergistic (cooperative) relationships among bacteria, fungi, and archaea which support nutrient cycling, modulate plant-microbe signaling, and maintain weed competitiveness under stress (Faust & Raes, 2012; Louca et al., 2016). (Table 4, Figure 2)

Table 4. Functional Roles of Weed-Associated Microbiomes

Function	Microbial Contributors	Mechanism	Example
Nutrient Acquisition	*Rhizobium, Bacillus, Azospirillum*	N fixation, P solubilization, siderophore production	*Amaranthus retroflexus*
Stress Tolerance	*Pseudomonas fluorescens, Bacillus subtilis*	Hormonal modulation, osmoprotectants, ROS scavenging	*Echinochloa crus-galli*
Allelopathy	*Fusarium, Alternaria*	Secondary metabolite production	*Amaranthus spp.*
Herbicide Adaptation	Various rhizosphere bacteria	Herbicide degradation	*Lolium rigidum*

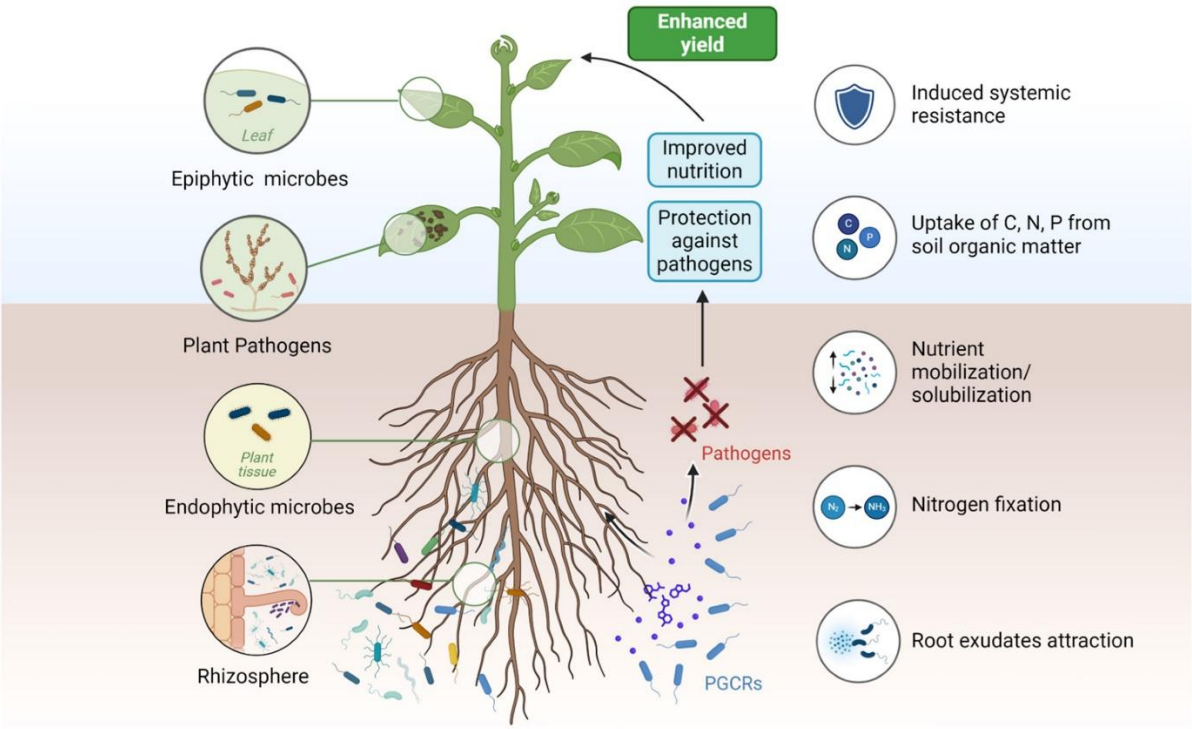


Figure 2. Functional roles of weed-associated microbiomes

APPLICATIONS IN SUSTAINABLE WEED MANAGEMENT

The information obtained from weed metagenomics can be employed to create environmentally friendly and sustainable weed management solutions such as bioherbicides, microbial inoculants, and integrated strategies (Santoyo et al., 2016; Berg & Raaijmakers, 2018).

Microbial Bioherbicides: The production of allelochemicals or enzymes may be harnessed in a means to directly suppress weed growth by Microorganisms. Examples are *Fusarium oxysporum* a pathogen for *Amaranthus* spp. and the seedling emergence inhibitory effect of *Trichoderma harzianum* on the reduction of the grass weed. Via metagenomics gene clusters accountable for the production of herbicidal metabolites can be pinpointed (Handelsman, 2004).

Microbial Inoculants: Beneficial microbes associated with weeds may be introduced into crops to achieve an increase in nutrient uptake and get a competitive advantage. Injection of maize with *Bacillus* strains from the *Echinochloa crus-galli* rhizosphere is an example of crop growth promotion and weed biomass reduction (Niu et al., 2017). Metagenomics facilitates the identification of plant growth-promoting strain traits leading to suitable formulations.

Integration with Cultural and Mechanical Practices: The effectiveness of microbial strategies mostly depends on their conjunction with other steps like crop rotation, cover cropping, mulching, and reduced-tillage systems that are compatible with Integrated Weed Management principles which aim at decreasing the use of chemical herbicides (Berg & Raaijmakers, 2018).

Precision Agriculture and Targeted Application: One of the major advantages when combining metagenomic data with GIS, remote sensing, and drones is pinpointing not only the location of weed hotspots but also the exact target delivery of microbial inoculants or bioherbicides, thus, the effectiveness is ensured, and the non-target impact is at a minimum (Vurukonda et al., 2018).

Monitoring and Feedback: This is continuous qPCR, metagenomics, or amplicon sequencing that enables tracking of microbial persistence, colonization, and community shifts, consequently, leading to optimal inoculant application and also to the desired weed suppression results (Turner et al., 2013).

Challenges and Limitations: Field variability, environmental factors, host specificity, regulation-related issues, and difficulties in commercialization may collectively lead to lowered efficacy as well as a limited number of those who adopt microbial strategies (Berg & Raaijmakers, 2018; EPA, 2020).

CHALLENGES

Weed metagenomics is confronted with problems. These issues encompass environmental variability, recruitment of host-specific microbiome, the complexity of datasets that requires advanced bioinformatics, and obstacles of regulative and commercial nature (Vurukonda et al., 2018; Bulgarelli et al., 2013; Quince et al., 2017; EPA, 2020).

FUTURE DIRECTIONS

The next research should consider an integrated multi-omics approach, discovering novel bioherbicide compounds, synthesizing microbial consortia, using precision agriculture for targeted microbial application, and conducting long-term field trials to check stability and effectiveness (Berg & Raaijmakers, 2018; Handelsman, 2004; Santoyo et al., 2016; Vurukonda et al., 2018; Turner et al., 2013).

CONCLUSION

Metagenomics-based research provides rich and deep insights into diversity, function, and relationships of weed-associated microbiomes. Microbes are the major contributors to nutrient acquisition, stress tolerance, allelopathy, as well as herbicide adaptation and therefore, they open.

REFERENCES

Berg, G., & Raaijmakers, J. M. (2018). Saving seed microbiomes. *The ISME Journal, 12*(5), 1167–1170. https://doi.org/10.1038/s41396-017-0028-2

Bulgarelli, D., Schlaeppi, K., Spaepen, S., Ver Loren van Themaat, E., & Schulze-Lefert, P. (2013). Structure and functions of the bacterial microbiota of plants. *Annual Review of Plant Biology, 64*, 807–838. https://doi.org/10.1146/annurev-arplant-050312-120106

Caporaso, J. G., Lauber, C. L., Walters, W. A., Berg-Lyons, D., Lozupone, C. A., Turnbaugh, P. J., Fierer, N., & Knight, R. (2010). Global patterns of 16S rRNA diversity at a depth of

millions of sequences per sample. *Proceedings of the National Academy of Sciences, 108*(Supplement 1), 4516–4522. https://doi.org/10.1073/pnas.1000080107
Carvalhais, L. C., Dennis, P. G., Badri, D. V., Kidd, B. N., Vivanco, J. M., & Schenk, P. M. (2015). Linking jasmonic acid signaling, root exudates, and rhizosphere microbiomes. *Molecular Plant-Microbe Interactions, 28*(9), 1049–1058. https://doi.org/10.1094/MPMI-01-15-0016-R
Duke, S. O. (2011). Why have no new herbicide modes of action appeared in recent years? *Pest Management Science, 68*(4), 505–512. https://doi.org/10.1002/ps.2333
Tesio, F, Ferrero, A. (2010). Allelopathy, a chance for sustainable weed management.The International Journal of Sustainable Development and World Ecology. 17, 377-389. https://doi.org/10.1080/13504509.2010.507402
EPA. (2020). *Guidance for registering microbial pesticides*. U.S. Environmental Protection Agency. https://www.epa.gov/pesticide-registration
Faust, K., & Raes, J. (2012). Microbial interactions: From networks to models. *Nature Reviews Microbiology, 10*(8), 538–550. https://doi.org/10.1038/nrmicro2832
Maksimov, I, Abizgil'dina, R., Pusenkova, L. (2011). Plant growth promoting rhizobacteria as alternative to chemical crop protectors from pathogens (review). Applied Biochemistry and Microbiology. 47. 333-345. https://doi.org/10.1134/S0003683811040090
Handelsman, J. (2004). Metagenomics: Application of genomics to uncultured microorganisms. *Microbiology and Molecular Biology Reviews, 68*(4), 669–685. https://doi.org/10.1128/MMBR.68.4.669-685.2004
Teske A , Biddle J.F., Edgcomb V.P., Schippers A. (2013). Deep subsurface microbiology: a guide to the research topic papers.Frontiers in Microbiology. 4.1664-302X. https://doi.org/10.3389/fmicb.2013.00122
Louca, S., Parfrey, L. W., & Doebeli, M. (2016). Decoupling function and taxonomy in the global ocean microbiome. *Science, 353*(6305), 1272–1277. https://doi.org/10.1126/science.aaf4507
Niu, B., Paulson, J. N., Zheng, X., & Kolter, R. (2017). Simplified and representative bacterial community of maize roots. *Proceedings of the National Academy of Sciences, 114*(12), E2450–E2459. https://doi.org/10.1073/pnas.1616148114
Oerke, E. C. (2006). Crop losses to pests. *Journal of Agricultural Science, 144*(1), 31–43. https://doi.org/10.1017/S0021859605005708
Prosser, J. I. (2012). Ecosystem processes and interactions in a morass of diversity. *FEMS Microbiology Ecology, 81*(3), 507–519. https://doi.org/10.1111/j.1574-6941.2012.01435.x
Quince, C., Walker, A. W., Simpson, J. T., Loman, N. J., & Segata, N. (2017). Shotgun metagenomics, from sampling to analysis. *Nature Biotechnology, 35*(9), 833–844. https://doi.org/10.1038/nbt.3935
Rodriguez, R. J., White Jr, J. F., Arnold, A. E., & Redman, R. S. (2009). Fungal endophytes: Diversity and functional roles. *New Phytologist, 182*(2), 314–330. https://doi.org/10.1111/j.1469-8137.2009.02773.x
Santoyo, G., Moreno-Hagelsieb, G., Orozco-Mosqueda, M. D. C., & Glick, B. R. (2016). Plant growth-promoting bacterial endophytes. *Microbiological Research, 183*, 92–99. https://doi.org/10.1016/j.micres.2015.11.008
Smith, S. E., & Read, D. J. (2008). *Mycorrhizal symbiosis* (3rd ed.). Academic Press.
Turner, T. R., James, E. K., & Poole, P. S. (2013). The plant microbiome. *Genome Biology, 14*(6), 209. https://doi.org/10.1186/gb-2013-14-6-209
Vurukonda, S. S. K. P., Vardharajula, S., Shrivastava, M., & SkZ, A. (2018). Enhancement of drought stress tolerance in crops by plant growth promoting rhizobacteria. *Microbiological Research, 184*, 13–24. https://doi.org/10.1016/j.micres.2015.12.003

ANALYSIS OF CERTAIN FACTORS CONTRIBUTING TO SOIL DEGRADATION PROCESSES IN THE SAATLI DISTRICT

Ph.D. Candidate Rashid Gasimov Tahir

Institute of Soil Science and Agrochemistry

ABSTRACT

This research analyzes the degradation processes of soils spread across the Saatli district located in the Mugan Plain of Azerbaijan, specifically focusing on meadow-gray soils, and the factors influencing them. The study determined that processes such as salinization, solonetzization (alkalization), deflation, and erosion have accelerated in the area due to intensive irrigation agriculture and anthropogenic impacts. The climatic, relief, and vegetation characteristics of the area, as well as the physicochemical indicators of the soils (particularly in the 0-25 cm layer), were examined. Consequently, the necessity of implementing complex meliorative and agrotechnical measures for the restoration and conservation of soil fertility has been substantiated.

Keywords: Degradation, Meadow-gray soils, Melioration, Saatli district, Salinization.

INTRODUCTION

Soil is one of the fundamental factors determining the ecological and economic potential of any region. This concept stems from the fact that soil resources, both as a natural asset and a means of production, directly affect almost all areas of human activity. Physical-chemical properties of the soil – such as its mechanical composition (clay, loam, sandy, etc.), organic matter content, degree of carbonation, cation exchange capacity, and pH level – determine the region's agricultural productivity, ecosystem sustainability, and the regeneration dynamics of natural resources. These parameters directly regulate the soil's ability to retain water and nutrients, the development of root systems, and the activity of microorganisms.

Obtaining high yields from cultivated crops in agriculture requires the maximum utilization of soils. This necessitates a rational yet scientifically grounded approach to land use, avoiding the increase of soil load beyond normal limits, and preserving long-term productivity. For instance, monoculture (cultivating the same crop in the same area every year) causes the rapid depletion of specific soil nutrients, whereas a scientifically grounded crop rotation system allows for the restoration of soil fertility.

This directly affects the ecological balance of the environment. Excessive land use, improper irrigation, and the application of chemical substances exceeding norms create changes in the ecosystem that are difficult to reverse. For example, the excessive use of pesticides and mineral fertilizers can lead to the destruction of soil microfauna, contamination of groundwater, and a reduction in biological diversity.

For this reason, the protection of soils cultivated under agricultural crops, and the environmental ecological balance in general, is considered a priority issue in the modern era. One of the main directions in modern agrarian policy is ensuring the sustainability of soil resources and preventing erosion, salinization, and other negative processes. Sustainable agriculture models, including precision farming and organic farming, meet precisely these requirements.

In recent years, increased attention to the agrarian sector in the republic and state programs adopted in this direction have placed significant importance on soil conservation and rational use. State programs adopted specifically for food security, the modernization of agriculture, and the expansion of melioration works constitute the basis of this process. The goal of these programs is not only short-term yield growth but also the preservation of soil resources for future generations.

To this end, the "State Program on Reliable Food Supply for the Population in the Republic of Azerbaijan" outlines many critical measures, including the identification of lands in need of melioration, the preparation of their maps, the restoration of degraded lands, the enhancement of soil fertility, and the return of developed lands in arid climates to crop rotation. These measures include the refinement of land-cadastre data, soil recultivation, the modernization of irrigation systems, and the application of meliorative technologies. For instance, the transition to drip irrigation systems increases water efficiency by 40-60%, thereby saving water resources and reducing the risk of soil salinization.

The Mugan Plain of our republic is one of the regions with the most ancient agriculture. Agricultural traditions formed over millennia, along with a soil structure rich in natural and anthropogenic changes, are observed in this plain. This is evidenced by traces of ancient irrigation canals and cultivation layers discovered as a result of archaeological research.

The continuous intensive use of soils spread in this area has resulted in degradation processes. Due to long-term irrigation, technical impacts, and the influence of chemical fertilizers, the soil structure has been disrupted, the mechanical composition has changed, and natural fertility levels have decreased. The disruption of soil structure leads to consequences such as the deterioration of water permeability and difficult aeration.

The soils spread in the researched Saatli district, particularly meadow-gray soils, are currently subject to degradation processes such as salinization, solonetzization, deflation, irrigation erosion, and pasture erosion. Each of these processes negatively affects the physical structure of the soil, its chemical composition, the accessibility of nutrients to plants, and the soil's hydro-physical properties. For example, salinization physiologically limits the water absorption capacity of plants due to the accumulation of excessive salts in the soil solution.

Many of these noted factors proceed more intensively due to anthropogenic factors. For example, improper irrigation, intensive animal husbandry, the inappropriate use of heavy machinery, and the failure to supply the soil with organic matter accelerate degradation. The use of heavy machinery causes soil compaction, making it difficult for roots to penetrate into the depths.

In this regard, researching the soil types spread in the Saatli district, specifically studying meadow-gray soils, and conducting work towards their protection is of great urgency. These soils constitute the main agricultural fund of the district, and their decline directly impacts food security. Their health directly determines the income source of the local population and the country's food supply.

RESEARCH AND FINDINGS

The Saatli district is located in the Mugan Plain of Azerbaijan and is distinguished by soil resources used primarily for agriculture. The economic profile of the district is linked to sectors such as crop production, vegetable growing, and animal husbandry, and the development of these sectors depends on soil resources. Cotton, grains, fodder crops, and various vegetables are widely cultivated here.

The Saatli district is located in the Kura-Araks Lowland of the republic. The climate is semi-desert and dry steppe, with an average annual precipitation of 187-300 mm and an average temperature of 14-15°C. These climate types indicate that aridity prevails in the soil formation process, making irrigation a crucial component of agriculture. Intensive evaporation in the summer months further accelerates the process of salt accumulation on the soil surface.

The territory is mainly flat, and the simplicity of the relief is one of the factors affecting soil formation. The flat relief allows for the uniform distribution of sediments, the proximity of groundwater to the surface, and the extensive application of irrigation systems. However, at the same time, the flatness of the relief can create drainage problems, which may lead to a rise in groundwater levels and soil salinization.

The vegetation cover of the area varies depending on relief, geographical position, groundwater levels, and climatic characteristics; the main natural vegetation cover consists of wormwood-ephemeral and wormwood-halophytic plant groups (Hasanov, 2021). These plant associations are characteristic of semi-desert ecosystems and are indicators of soil salinity levels. Halophytic plants, such as species of saltwort growing in saline areas, are distinguished by their salt tolerance, and their presence indicates a salt problem in the soil.

This soil type forms along the banks of the Araz River, near irrigation systems. The moisture regime is relatively good, and it possesses high potential for agriculture because the Araz River brings alluvial materials rich in sediments, increasing soil fertility. Alluvial deposits give the soil good water and air permeability properties as they contain clay, sand, silt, and organic residues.

From the research conducted by M.P. Babayev, it becomes clear that the construction of irrigation and collector-drainage networks in the Saatli district, as well as the expansion and development of irrigation agriculture, have affected and changed the morphogenetic and other characteristics of the soils spread in this area, resulting in differences according to the soil types to which they belong. This has caused the transformation of chemical, physical, and biological indicators of the soils. In other words, human activity has decisively intervened in the soil formation process.

As a result, two "cultivated" subtypes of gray soils at different levels are currently encountered in the research area (Babayev, 1984). That is, these soils have acquired different characteristics depending on the intensity of irrigation, the quality of drainage, and anthropogenic impact. "Cultivated" soils are those that have diverged from their original natural state but possess high value for agriculture.

The soils of this region are primarily fertile and suitable for cultivation. However, this fertility can only be sustained long-term with a proper management system. Soil fertility is not a static state but a dynamic indicator that increases or decreases depending on management.

However, there are also many soils in the area that are saline and have unsatisfactory hydro-physical properties. Structural problems of these soils limit agricultural activity and require melioration measures. Methods such as chemical melioration (e.g., gypsum application), leaching irrigation, or the cultivation of salt-tolerant plants can be applied for the restoration of such soils.

These soils compact when dry, forming a thick crust and deep cracks. When wet, they turn into a structureless mass, and water permeability decreases. These physical changes weaken the agrotechnical qualities of the soil and hinder the normal development of the root system. This is particularly evident in soils with heavy mechanical composition (clay).

This, in turn, worsens agricultural work, and the development of agricultural crops does not proceed normally in such soils (Azizov, 1991). Productivity decreases, water consumption increases, and the efficiency of fertilizers drops. For instance, in soil that has lost its structure, water creates surface runoff; since moisture does not signal to the soil depth, water consumption increases, and fertilizers are washed away.

The main soil types spread in the researched area are Meadow-gray, Irrigated meadow-gray, Alluvial meadow, Meadow-boggy, and Saline soils. Each soil type has unique characteristics, water regimes, and degrees of suitability for agriculture. For example, Meadow-boggy soils are located in areas where groundwater is very close to the surface, and drainage is primarily required to make them suitable for use.

Meadow-gray soils are the most widespread soil type in the research area. This is related to their formation in accordance with natural-geographic conditions. Since they form under semi-hydromorphic conditions – that is, conditions of temporary excess moisture – they correspond to the climatic and hydrological characteristics of the region.

Formed under high humidity conditions, this soil type has developed morphologically in a semi-hydromorphic regime. This condition determines the soil's carbonation, the form of the humus layer, and the water-air regime. The semi-hydromorphic regime leaves traces of gley processes (reduction of iron compounds in oxygen-free conditions) in the soil profile, which manifests as gray-green spots in the profile cross-section.

On the other hand, groundwater close to the surface has also influenced the soil formation process (Feyziyev, 2016). The rise of groundwater can cause salts to rise to the surface, leading to soil salinization. As a result of capillary rise, salts dissolved in groundwater rise to the upper layers and surface of the soil, accumulating there due to evaporation.

CONCLUSION AND DISCUSSION

It has been determined through our research that the degradation process has a significant impact on the chemical composition of meadow-gray soils. In particular, the amount of humus, the level of nutrients, and the soil's absorption capacity decrease. The decrease in humus also causes the disruption of the soil structure, as organic matter acts as the main adhesive binding soil particles.

Thus, research conducted in the arable layer (0-25 cm) of the soils revealed that the main causes for the loss of fertility due to degradation in these soils are salinization and a scarcity of nutrients and organic matter. These changes directly weaken soil productivity. Since this layer is the zone where more than 90% of plant roots are concentrated and where the most active biochemical processes occur, its condition is of critical importance.

Consequently, the conducted studies show that the Saatli district possesses diversity in terms of soil resources. This diversity is linked to both natural-geographic and anthropogenic factors. Such diversity necessitates the development of individual approaches and management strategies for each soil plot.

While some soils allow for high productivity, strictly meliorative measures are required for others. Measures such as irrigation norms, drainage networks, and fertilization systems are of vital importance for these soils. A correctly calculated irrigation norm meets the plant's water needs and helps leach salts from the soil; however, water in excess of the norm can cause groundwater levels to rise.

To fully utilize the district's agricultural potential, agrotechnical and technogenic measures must be implemented in a planned manner, taking soil types into account. Only in this case can soil resources be managed sustainably and productivity increased. This can be achieved through the integration of soil maps, Geographic Information Systems (GIS), and precision farming technologies, which allow for the application of resources (water, fertilizers, pesticides) in optimal doses for each specific area.

REFERENCES

Babayev, M. P. (1984). *Irrigated Soils of the Kura-Araks Lowland and Their Productive Capacity* [Орашаемые почвы Кура-Араксинской низменности и их производительная способность]. Baku: Elm.

Azizov, Q. Z. (1991). Main factors causing the decline in the efficiency of agricultural production in meliorated soils and ways to increase soil fertility. *Materials of the Republican Scientific Conference on "The Role of Melioration Science in Increasing the Fertility of Irrigated Soils in the Republic of Azerbaijan"* (pp. 52-60). Baku.

Feyziyev, F. M. (2016). *Morphogenetic Diagnostics of Meadow-Gray Soils of the Mugan Plain and Their Study via Remote Sensing Technology* (Abstract of the dissertation for the degree of Doctor of Philosophy in Biology). Baku.

Hasanov, V. (2021). *Morphogenetic Diagnostics, Classification of Alluvial Hydromorphic Soils of Azerbaijan and Subtropical Features of the Gleying Process*. Baku: Elm.

CHANGES IN SERUM PARAOXONASE-1 ACTIVITY DURING ESTRUS IN PROGESTERONE-BASED SYNCHRONIZED GURCU GOATS DURING PERIODS BREEDING SEASON AND NON-BREEDING SEASON

ÜREME MEVSİMİ VE DIŞI DÖNEMLERDE PROGESTERON DESTEKLİ SENKRONİZE EDİLEN GÜRCÜ KEÇİLERİNDE ÖSTRUS ESNASINDA SERUM PARAOKSANAZ-1 AKTİVİTESİNİN DEĞİŞİMİ

Assist. Prof. Dr. Serpil AYGÖRMEZ

Department of Biochemistry, Faculty of Veterinary Medicine, Kafkas University, Kars, Türkiye

Prof. Dr. Mushap KURU

Department of Obstetrics and Gynecology, Faculty of Veterinary Medicine, Kafkas University, Kars, Türkiye

Assoc. Prof. Dr. Mustafa MAKAV

Department of Physiology, Faculty of Veterinary Medicine, Kafkas University, Kars, Türkiye

ÖZET

Bu çalışmada üreme mevsimi ve dışı dönemlerde progesteron destekli senkronize edilen Gürcü keçilerinde, serum malondialdehit (MDA), glutatyon (GSH) düzeyleri ile paraoksanaz-1 (PON) aktivitesinin değişiminin belirlenmesi amaçlanmıştır. Çalışmada 30 adet keçi (15 keçi sezon içi Gürcü keçisi ve 15 keçi sezon dışı) kullanılmıştır. Östrus senkronizasyonu amacıyla, keçilere progesteron içeren süngerler 7 gün kalacak şekilde vaginaya yerleştirildi. Progesteron içeren süngerlerin çıkarıldığı gün tüm keçilere 500 IU kısrak koryonik gonadotropini (eCG) ve prostaglandin F2α (PGF2α) kas içi enjeksiyonları yapıldı. Daha sonra keçiler arasına östrus tespiti için teke katıldı ve östrus belirtileri gösteren keçiler tespit edildi. Östrus senkronizasyonuna başlamadan ve östrusta olmak üzere keçilerden kan alındı. Keçilerden alınan kandan serum MDA, GSH düzeyleri ve PON aktivitesi belirlendi. Elde edilen verilere göre, Gürcü keçilerin üreme mevsiminde ($p<0.01$) ve dışında ($p<0.001$) MDA düzeyi arttı ve zaman etkisi anlamlıydı ($p<0.001$). Ayrıca MDA düzeyinde grup etkisi ve grup × zaman interaksiyonunun istatistiksel olarak anlamlıydı ($p=0.02$). GSH, Gürcü keçilerinde üreme mevsimi dışında azaldı ($p<0.05$) ve üreme mevsiminde ise arttı ($p<0.05$). Ayrıca GSH'da grup × zaman interaksiyonu istatistiksel olarak anlamlıydı ($p=0.003$). Gürcü keçilerin üreme mevsimi dışında PON aktivitesi azaldı ($p<0.01$) ve üreme mevsiminde ise arttı ($p<0.05$). Fakat PON aktivitesinde grup × zaman interaksiyonu istatistiksel olarak anlamlıydı ($p<0.001$). Sonuç olarak, üreme mevsimi ve dışı dönemlerde progesteron destekli senkronize edilen Gürcü keçilerinde MDA, GSH düzeylerinin ve PON aktivitesinin değişiminin değerlendirilmesi bu dönemlerin izlenmesi için faydalı biyobelirteçler olabilir.

Anahtar kelimeler: Üreme mevsimi, Üreme mevsimi dışı, Gürcü keçi, Oksidatif statü, Paraoksanaz-1

ABSTRACT

This study aimed to determine the changes in serum malondialdehyde (MDA), glutathione (GSH) levels and paraoxonase-1 (PON) activity in progesterone-based synchronized Gurcu goats during breeding season and non-breeding season. 30 goats (15 Gurcu goats in breeding season and 15 goats non-breeding season) were used in the study. For the purpose of estrus synchronization, sponges containing progesterone were placed in the vagina of the goats for 7 days. On the day the progesterone-containing sponges were removed, all goats received intramuscular injections of 500 IU mare chorionic gonadotropin (eCG) and prostaglandin F2α (PGF2α). Then, a goat was added to the goats to detect estrus, and goats showing signs of estrus were detected. Blood was taken from the goats before estrus synchronization and during estrus. Serum MDA, GSH levels and PON activity were determined from blood taken from goats. According to the data obtained, MDA levels increased in Gurcu goats during breeding season ($p<0.01$) and non-breeding season ($p<0.001$) and the time effect was significant ($p<0.001$). In addition, the group effect and group × time interaction at the MDA level were statistically significant ($p = 0.02$). GSH decreased in Gurcu goats non-breeding season ($p<0.05$) and increased during the breeding season ($p<0.05$). Additionally, the group × time interaction in GSH was statistically significant ($p = 0.003$). PON activity of Gurcu goats decreased non-breeding season ($p<0.01$) and increased during the breeding season ($p<0.05$). However, the group × time interaction in PON activity was statistically significant ($p<0.001$). As a result, evaluation of the changes in MDA, GSH levels and PON activity in progesterone-based synchronized Gurcu goats during periods breeding season and non-breeding season may be useful biomarkers for monitoring these periods.

Key words: Breeding season, Non-breeding season, Gurcu goat, Oxidative status, Paraoxonase-1

INTRODUCTION

In many regions of the world, products obtained from goat farming, such as meat and milk, have maintained their seasonality (Balaro et al., 2019). Goats, one of the oldest domesticated animal species, are one of the animals in tropical and subtropical regions and have unique biological characteristics (Hussain et al., 2020). Due to the social and economic conditions of farmer families, goat breeding is mostly done in the Mediterranean, Aegean and Southeastern Anatolia regions of Türkiye (Kuru et al., 2024). Gurcu goats, which came from the Caucasus to Anatolia, do not show reproductive problems such as uterine infection, follicular cysts, miscarriage, infertility, and are adapted to the cold climate conditions of the region. They offer alternatives to cattle breeding for farmers, but their numbers have not increased significantly (Kuru et al., 2019; Boğa Kuru et al., 2024; Kuru et al., 2024). Goats are seasonally breeding by nature, which is associated with changes in annual photoperiod. The breeding season, stimulated by the decrease in daylight hours in autumn and winter, results in birth in the spring months (Nogueira et al., 2015; Rehman et al., 2021; Shl et al., 2025). This long period makes the availability of milk and meat difficult (Zarazaga et al., 2011). Although farmers try to eliminate this problem by extending the lactation period, this affects milk production (Desire et al., 2018). The use of estrus synchronization during anestrus increases reproductive efficiency and enables more than one offspring per year (Osman & Elzagafi, 2016; Duan et al., 2025). Estrus synchronization practices are adopted to stimulate and control estrus and ovulation during breeding season and non-breeding season (Van et al., 2022; Duan et al., 2025). Additionally, estrus synchronization is a practical method to increase reproductive performance (Sen & Onder, 2016; Alvarado-Espino et al., 2019; El-Tarabany et al., 2020). The estrus synchronization method is one of the goat breeding methods that focuses on the creation and

extension of the luteal phase (Hussain et al., 2020). For this purpose, synthetic analogs such as progesterone are exogenous hormones for estrus and estrus synchronization in goats (Sen & Onder, 2016; Cetin et al., 2024). In addition, mare chorionic gonadotropin (eCG) is administered together with progesterone the non-breeding season to increase both estrus and ovulation (Balaro et al., 2019; Rehman et al., 2021; Cosentino et al., 2024; Cortes et al., 2025). In addition, prostaglandin F2α (PGF2α) is used to synchronize estrus through the regression of the corpus luteum (Osman & Elzagafi, 2016; El-Mokadem et al., 2022). Oxidative stress, which occurs as a result of decreased antioxidant defense or increased production of oxidants such as reactive oxygen species, is the imbalance between radical scavenging and generation (Teama, 2018; Mohamed et al., 2021). Malondialdehyde (MDA), the most important molecule in cellular degeneration caused by free radicals, is the end product of oxidative destruction of lipids (Kuru et al., 2018). The best-known natural low molecular weight antioxidant is glutathione (GSH) (Mohamed et al., 2021). The antioxidant enzyme paraoxonase-1 (PON) is found in serum, kidney, liver and intestine (Kuru et al., 2020).

The aim of this study was to determine the changes in serum PON activity and MDA and GSH levels during estrus in progesterone-based synchronized Gurcu goats during the breeding season and non-breeding periods.

MATERIALS AND METHODS

Ethical approval and farm permit

Before starting the study, approval was obtained from the Kafkas University Animal Experiments Local Ethics Committee (KAU-HADYEK) with the number KAU-HADYEK/2025-169 and from the Kafkas University Prof. Dr. Ali Rıza AKSOY Education-Research and Application Farm with the session number 2024/2025-15 and decision number 23.

Animals

Total of 30 Gurcu goats, aged between 3 and 4 years, clinically healthy, with a body weight of 40-50 kg, in breeding season (n=15) and non-breeding season (n=15), from Kafkas University Prof. Dr. Ali Rıza AKSOY Training-Research and Application Farm, were used as animal material in the study.

Estrus synchronization and mating procedures

For estrus synchronization, progesterone-containing sponges (Esponjavet®, Hipra, Türkiye) were inserted into the vagina of goats for 7 days. On the day the progesterone-containing sponges were removed, all goats received intramuscular injections of 500 IU eCG (Oviser®, Hipra Animal Health, Türkiye) and PGF2α (Dinoprost, Dinolytic®, Zoetis, Türkiye). Later, a male was added to the goats to detect estrus, and goats showing signs of estrus were identified (Kuru 2022, 2023; Kuru & Boğa 2024).

Biochemical analyses

Before starting synchronization, blood was collected from all goats determined to be in estrus and from the jugular vein into 8.5 mL gel-vacuum (BD Vacutainer®, Becton, Dickinson and

Company, USA) tubes. The collected blood samples were centrifuged at 3000 rpm for 10 minutes and then stored at -20°C until the serum samples were analyzed.

Serum MDA analysis was performed using the method of Yoshioka et al., (1979). GSH analysis was analyzed spectrophotometrically at 412 nm according to the method of Beutler et al., (1963). PON activity was determined colorimetrically using the Rel Assay Diagnostics® (Gaziantep, Türkiye) kit.

Statistical analyses

Statistical analyses of the data obtained in the study were performed using the GraphPad Prism® (Version 10, GraphPad Software Inc., San Diego, USA) statistical program. The Shapiro-Wilk test was used to determine whether the obtained data showed a normal distribution according to the groups. The repeated measurements analysis of variance method was used in the analysis of measured marker data. Statistical analyses of group, time, and group × time interactions were performed. Additionally, Fisher's LSD was applied for pairwise comparisons of parameters between days and between groups on the day of sampling. All results are shown as mean ± standard deviation (SD). $P<0.05$ was considered statistically significant in the analysis results.

RESULTS

Serum MDA level

The results of MDA levels during estrus in Gurcu goats synchronized with progesterone during the breeding season and non-breeding periods are shown in Figure 1. According to the obtained data, MDA levels of Gurcu goats increased during ($p<0.01$) and non-breeding season ($p<0.001$) the breeding season and the time effect was significant ($p<0.001$). Additionally, the group effect ($p=0.05$) and group × time interaction at MDA level were statistically significant ($p=0.02$). Again, MDA was statistically higher during estrus non-breeding season than within the breeding season ($p<0.01$).

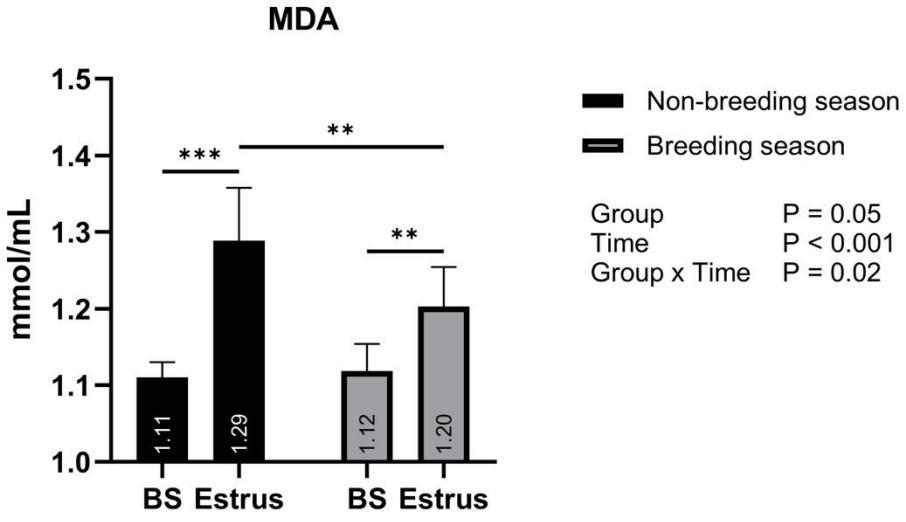


Figure 1: Changes in serum MDA levels during estrus in Gurcu goats synchronized with progesterone during breeding season and non-breeding season. MDA: Malondialdehyde, BS: Before synchronization **: $p<0.01$, ***: $p<0.001$.

Serum GSH level

Serum GSH levels decreased during estrus, the non-breeding season ($p<0.05$), and increased during the breeding season ($p<0.05$). Additionally, group × time interaction in GSH was statistically significant ($p=0.003$). Again, the GSH level before the start of estrus synchronization was higher non-breeding season than during the breeding season ($p<0.05$). The opposite situation was recorded during estrus, and the GSH level during estrus non-breeding season was statistically lower than during the breeding season ($p<0.05$) (Figure 2).

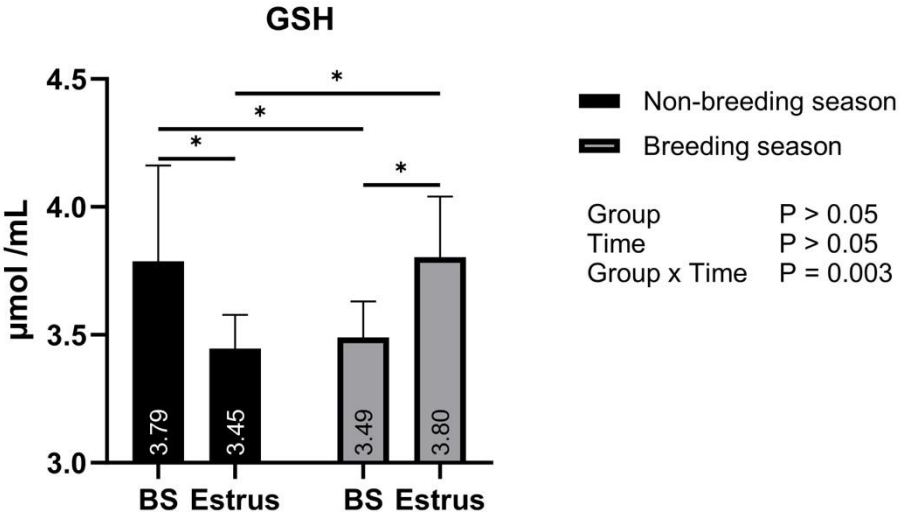


Figure 2: Serum GSH levels during estrus in Gurcu goats synchronized with progesterone during breeding season and non-breeding season. GSH: Glutathione, BS: Before synchronization *: $p<0.05$.

Serum PON activity

The change of PON activity during estrus in progesterone-supported synchronized Gurcu goats during the breeding and non-breeding seasons is shown in Figure 3. In Gurcu goats, PON activity decreased during estrus non-breeding season ($p<0.01$) and increased during the breeding season ($p<0.05$). However, group × time interaction in PON activity was statistically significant ($p<0.001$). Again, serum PON activity before synchronization non-breeding season was higher than during the breeding season ($p<0.001$). The opposite situation was observed during estrus, and PON activity was lower in estrus than in the non-breeding season ($p<0.001$) (Figure 3).

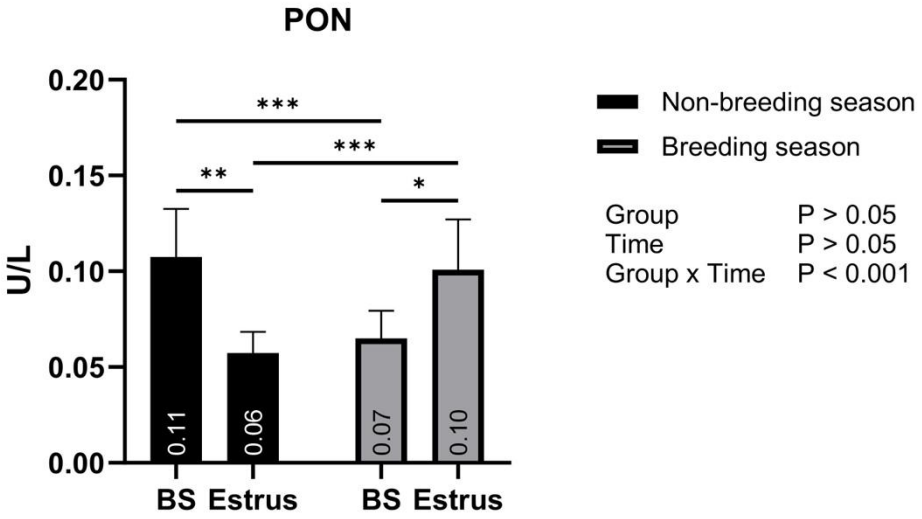


Figure 3: Changes in serum PON activity during estrus in Gurcu goats synchronized with progesterone during breeding season and non-breeding season. PON: Paraoxonase-1, BS: Before synchronization *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$.

CONCLUSION

In Gurcu goats, MDA increased during both breeding season and non-breeding season, and PON activity and GSH decreased non-breeding season and increased during the breeding season. Increased MDA levels in Gurcu goats, as an indicator of lipid peroxidation during breeding season and non-breeding season, indicate that oxidative stress is experienced. The decrease in GSH level and PON activity non-breeding season is an indication of a decrease in antioxidant capacity. These parameters show that they can be used as potential biomarkers in goats during breeding season and non-breeding season. Additionally, it has been demonstrated that oxidative stress and antioxidant capacity during estrus show seasonal differences. The increase in MDA levels and the decrease in GSH and PON activity during estrus, especially non-breeding season, indicate that antioxidant defense is inadequate. On the other hand, the increase in GSH and PON activity during the breeding season reveals that endogenous antioxidant mechanisms work more effectively during this period. The basis of this difference is that estrogen levels synthesized in each cycle, regardless of synchronization during the breeding season, may limit the oxidative stress load by increasing the activity of antioxidant enzymes. Therefore, seasonal changes in steroid hormone fractions, especially estrogen, are thought to play a critical role in the regulation of antioxidant-oxidant balance. However, more comprehensive studies with larger sample sizes should be conducted to better understand the physiological and biochemical changes experienced in Gurcu goats during breeding activities during breeding season and non-breeding season.

REFERENCES

Alvarado-Espino, A. S., Menchaca, A., Meza-Herrera, C. A., Mellado, M., Arellano, F., & Véliz, F. (2019). Use of injectable progesterone and hCG for fixed-time artificial insemination during the non-breeding season in goats. *Theriogenology*, *127*, 21-25.

Balaro, M. F. A., de Mello, S. G. V., da Silva Santos, A., Cavalcanti, L. M., Almosny, N. R. P., Fonseca, J. F., & Brandão, F. Z. (2019). Reproductive seasonality in Saanen goats kept under tropical conditions. *Tropical Animal Health and Production*, *51*(2), 345-353.

Beutler, E. Duron, O. and Kelly, B. M. (1963). Improved method for the determination of blood glutathione. *Journal of Experimental and Clinical Medicine, 61,* 882-888.

Boğa Kuru, B., Akyüz, E., Aydın, U., Kuru, M., Bektaşoğlu, F., Sezer, M., Yıldız, U., & Kırmızıbayrak, T. (2024). Effect of birth type and sex on growth performance, wither height, humerus-radius bone dimensions, humerus–ulna growth plate width and selected hormone profile in growing Gurcu goat kids. *Veterinary Medicine and Science*, *10*(5), e70013.

Cortes, L. R., Rodrigues, J. N. D., Vergani, G. B., Figueira, L. M., Rangel, P. S. C., Batista, R. I. T. P., Freitas, B. W., Brandao, F. Z., Souza-Fabjan, J. M. G., & Fonseca, J. F. (2025). Effects of adding equine chorionic gonadotropin (eCG) to cloprostenol-based estrus synchronization protocol on luteogenesis, pregnancy rate, and embryo development in cyclic dairy goats. *Small Ruminant Research*, *251*, 107568.

Cosentino, I. O., Balaro, M. F. A., Leal, F. S. C., de Figueiredo Cardoso Barbosa, L., Gonçalves, F. M., & Brandão, F. Z. (2024). The male effect associated with prostaglandins and reproductive outcomes in photo-stimulated Saanen goats during the non-breeding season. *Reproduction in Domestic Animals*, *59*(6), e14651.

Cetin, N., Kosal, V., Kuru, M., Oner, A. C., & Eski, F. (2024). The effect of hCG administration on reproductive performance in undernourished lactating hair goats synchronized during non-breeding season. *Acta Veterinaria Brno*, *93*(3), 339-345.

Desire, S., Mucha, S., Coffey, M., Mrode, R., Broadbent, J., & Conington, J. (2018). Pseudopregnancy and aseasonal breeding in dairy goats: genetic basis of fertility and impact on lifetime productivity. *Animal*, *12*(9), 1799-1806.

Duan, Z., Liu, M., Li, J., Liu, K., Qi, Q., Yu, Z., Samoo, H. A., Wang, C., & Hou, J. (2025). Melatonin Implantation Improves the Reproductive Performance of Estrus-Synchronized Ewes During Seasonal Anestrus and Enhances the Antioxidant and Steroidogenic Capacities of Granulosa and Luteal Cells. *Antioxidants*, *14*(7), 895.

El-Mokadem, M. Y., Ramadan, T. A., & Rashad, A. M. A. (2022). Impact of usıng cıdr-ecg protocol durıng out-of-breedıng season on reproductıve seasonalıty of anglo-nubıan and baladı does. *Egyptian Journal of Animal Production*, *59*(4), 91-96.

El-Tarabany, A. A., Atta, M. A., & El-Tarabany, M. S. (2020). Impact of breeding season on hormonal profile and some biochemical parameters at different stages of pregnancy in Baladi goats. *Biological Rhythm Research*, *51*(4), 552-559.

Hussain, K. A., Hussain, S. O., & Zalzala, S. J. (2020). Cortisol and Luteinizing hormones concentration in relation to estrus synchronization and investigation of estrus time and parturition in Shami goats by ultrasonography. *Biochemical & Cellular Archives*, *20*(2), 4909-4913.

Kuru, M., Öğün, M., Kulaksız, R., Kükürt, A., & Oral, H. (2018). Comparison of Oxidative/Nitrosative Stress, Leptin and Progesterone Concentrations in Pregnant and Non-pregnant Abaza Goats Synchronized with Controlled Internal Drug Release Application. *Kafkas Üniversitesi Veteriner Fakültesi Dergisi*, *24*(6), 887-892.

Kuru, M., Oral, H., & Kulaksiz, R. (2019). Determination of gestational age by measuring defined embryonic and foetal indices with ultrasonography in Abaza and Gurcu goats. *Acta Veterinaria Brno*, *87*(4), 357-362.

Kuru, M., Kükürt, A., Akyüz, E., Oral, H., Kulaksız, R., & Karapehlivan, M. (2020). Paraoxonase activities, total sialic acid concentration and lipid profile after use of controlled internal drug release (CIDR) in Gurcu goats. *International Journal of Veterinary Science*, *9*(4), 517-522.

Kuru M (2022). The effect of progesterone-based estrus synchronization on pregnancy rate during the breeding or non-breeding season in Gurcu goats. Akdeniz 8th International Conference on Applied Sciences, November 19-20, pp 212-219.
Kuru M (2023). The effect of progesterone-supported estrus synchronization during the breeding season on the pregnancy rate in Abaza and Gurcu goats. Ege 10th International Conference on Applied Sciences, 22-24 Aralık, İzmir pp: 2200-2209.
Kuru M, Boğa Kuru B (2024). The effect of different durations of progesterone based estrus synchronization on pregnancy rates in Gurcu goats during the breeding season: A review of studies from 2016 to 2024. 8th International Congress on Advances in Bioscience and Biotechnology (ICABB), September 23-27, pp: 91-100.
Kuru, M., Makav, M., Kuru, B. B., Bektaşoğlu, F., Demir, M. C., Bulut, M., & Alwazeer, D. (2024). Hydrogen-rich water supplementation improves metabolic profile during peripartum period in Gurcu goats and enhances the health and survival of kids. *Research in Veterinary Science*, *171*, 105208.
Mohamed, R. H., Khalphallah, A., Nakada, K., Elmeligy, E., Hassan, D., Ebissy, E. A., Ghandour, R. A., Mousa, S. A., & Hassaneen, A. S. (2021). Clinical and correlated responses among steroid hormones and oxidant/antioxidant biomarkers in pregnant, non-pregnant and lactating CIDR-pre-synchronized dromedaries (Camelus dromedarius). *Veterinary Sciences*, *8*(11), 247.
Nogueira, D. M., Cavalieri, J., Gummow, B., & Parker, A. J. (2015). Comparison of follicular dynamics and hormone profiles in Boer goats examined during the breeding and non-breeding seasons in the tropics of Queensland, Australia. *Small Ruminant Research*, *125*, 93-100.
Osman, E. E. I., & Elzagafi, M. H. (2016). Effect of two PF2α injections on estrous synchronization and some reproductive traits during non breeding season in desert goats. *Internatıonal Journal of Veterinary Science, 5*(4), 299-301.
Rehman, A., Ahmad, E., Arshad, U., Riaz, A., Akhtar, M. S., Ahmad, T., Khan, J. A., Mohsin, I., Shi, Z., & Sattar, A. (2021). Effects of immunization against inhibin α-subunit on ovarian structures, pregnancy rate, embryonic and fetal losses, and prolificacy rate in goats where estrus was induced during the non-breeding season. *Animal Reproduction Science*, *224*, 106654.
Sen, U., & Onder, H. (2016). The effect of estrus synchronization programmes on parturition time and some reproductive characteristics of Saanen goats. *Journal of Applied Animal Research*, *44*(1), 376-379.
ShI, C., Liu, Q., Wang, W., He, Q., Zhao, J., Zhang, F., Zhu, L., & Luo, J. (2025). Transcriptome and Proteome of Ovarian Revealed the Differences in the Ovaries of Dairy Goats During the Breeding and Non-breeding Seasons. *Frontiers in Veterinary Science*, *12*, 1565807.
Teama, F. E. I. (2018). Evaluation of some oxidative-stress and antioxidant markers in goats during estrous cycle under Egyptian environmental conditions. *Revista Brasileira de Zootecnia*, *47*, e20160382.
Van, N. K., Huong, V. T. T., Huu, Q. X., Hieu, P. T., & Lan, P. D. (2022). The effects of the oestrus ınductıon methods on the estrous synchronızatıon ın goats. *Journal of Animal Husbandry Sciences and Technics (JAHST)*, 81.
Yoshioka, T. Kawada, K. Shimada, T. and Mori, M. (1979). Lipid peroxidation in maternal and cord blood and protective mechanism against activated-oxygen toxicity in the blood. *American Journal of Obstetrics and Gynecology, 135*(3), 372-376.
Zarazaga, L. A., Gatica, M. C., Celi, I., Guzmán, J. L., & Malpaux, B. (2011). Artificial long days and daily contact with bucks induce ovarian but not oestrous activity during the non-breeding season in Mediterranean goat females. *Animal Reproduction Science*, *125*(1-4), 81-87.

CURRENT APPROACHES, APPLICATIONS AND FUTURE PERSPECTIVES IN TRANSGENIC ANIMAL BIOTECHNOLOGY

TRANSGENİK HAYVAN BİYOTEKNOLOJİSİNDE GÜNCEL YAKLAŞIMLAR, UYGULAMALAR VE GELECEK PERSPEKTİFLERİ

Doç. Dr. Mehmet YARDIMCI

Tekirdağ Namık Kemal Üniversitesi, Veteriner Fakültesi, Zootekni ve Hayvan Besleme Bölümü, Tekirdağ, Türkiye.

https://orcid.org/0000-0001-5650-437X

ABSTRACT

Transgenic animal biotechnology has become a technology gaining strategic importance in many fields, including agriculture, animal husbandry, medicine, industry, and environmental management, thanks to rapid advances in molecular biology and genome editing techniques. Microinjection, embryonic stem cell manipulation, viral vectors, somatic cell nuclear transfer (SCNT), and, in particular, CRISPR-Cas systems allow for highly precise genetic modification in various species. This allows for significant improvements in recombinant protein production, disease resistance, growth performance, and product quality. Transgenic approaches offer the potential to both increase the nutritional value of animal products and reduce ecosystem pressure by supporting environmental sustainability. Furthermore, promising results in xenotransplantation studies of genetically modified pigs have made significant contributions to biomedical research. However, technical limitations such as random gene integration, mosaicism, and epigenetic uncertainties, as well as ethical and ecological concerns, are key factors to consider when utilizing this technology safely. In conclusion, transgenic animal biotechnology is a rapidly developing field that is expected to find wider application in the future, and the sustainability of this progress depends on the meticulous execution of ethical principles and risk assessments.

Keywords: Transgenic animal, genomic, gen editing

ÖZET

Transgenik hayvan biyoteknolojisi, moleküler biyoloji ve genom düzenleme tekniklerindeki hızlı ilerlemeler sayesinde tarım, hayvancılık, tıp, endüstri ve çevre yönetimi gibi birçok alanda stratejik önem kazanan bir teknoloji hâline gelmiştir. Mikroenjeksiyon, embriyonik kök hücre manipülasyonu, viral vektörler, somatik hücre çekirdeği transferi (SCNT) ve özellikle CRISPR-Cas sistemleri farklı türlerde yüksek doğrulukla genetik modifikasyon yapılmasına olanak tanımaktadır. Bu sayede rekombinant protein üretimi, hastalık direnci, büyüme performansı ve ürün kalitesinde önemli iyileşmeler elde edilmektedir. Transgenik yaklaşımlar, hem hayvansal ürünlerin besin değerini artırmakta hem de çevresel sürdürülebilirliği destekleyerek ekosistem üzerindeki baskıyı azaltma potansiyeli sunmaktadır. Bunun yanı sıra genetiği düzenlenmiş

domuzların ksenotransplantasyon çalışmalarında umut verici sonuçlar vermesi, biyomedikal araştırmalara önemli katkılar sağlamaktadır. Ancak rastgele gen entegrasyonu, mozaiklik ve epigenetik belirsizlikler gibi teknik sınırlılıkların yanı sıra etik ve ekolojik kaygılar, bu teknolojinin güvenli kullanımında dikkate alınması gereken temel unsurlardır. Sonuç olarak, transgenik hayvan biyoteknolojisi hızla gelişen ve gelecekte daha geniş uygulama alanı bulması beklenen bir alan olup, bu ilerlemenin sürdürülebilir olması etik ilkelerin ve risk değerlendirmelerinin titizlikle yürütülmesine bağlıdır.

Anahtar kelimeler: Transgenik hayvan, genomik, gen düzenleme

GİRİŞ

Moleküler biyoloji, genomik ve gen düzenleme teknolojilerinde son yıllarda kaydedilen hızlı ilerlemeler, hayvan genomunun yüksek hassasiyetle modifiye edilmesini mümkün kılarak transgenik hayvan üretimini modern biyoteknolojinin temel araştırma ve uygulama alanlarından biri hâline getirmiştir.

Transgenik hayvan, türler arası gen transferi, hedeflenmiş mutasyon oluşturma, genom düzenleme veya endojen genlerin yeniden yapılandırılması yoluyla yeni bir fenotip kazandırılmış organizma olarak tanımlanmaktadır (Shakweer ve ark., 2023).

İlk transgenik farelerin 1980'lerde elde edilmesinden bu yana mikroenjeksiyon, embriyonik kök hücre manipülasyonu, viral vektör kullanımı, somatik hücre çekirdeği transferi (SCNT) ve CRISPR-Cas tabanlı sistemler gibi yöntemlerde dikkate değer teknik gelişmeler sağlanmıştır (Park, 2023).

Bu teknik yenilikler, çok sayıda hayvan türünde başarılı transgenik hatların oluşturulmasına olanak vermiş ve hayvancılık, tıp, farmasötik protein üretimi ve çevresel sürdürülebilirlik gibi çeşitli alanlarda önemli uygulama potansiyelleri ortaya çıkarmıştır.

Gen düzenleme araçlarının doğruluk, etkinlik ve hedeflenme kapasitesinde kaydedilen ilerlemeler sayesinde sığır, koyun, keçi, domuz, tavuk, balık ve primatlar dâhil birçok türde transgenik veya genetiği düzenlenmiş hatlar yüksek başarı oranlarıyla geliştirilebilmektedir (Popova ve ark., 2023; Hallerman ve ark., 2023).

Bu biyoteknolojik yenilikler tıp, tarım, hayvansal üretim, endüstriyel protein sentezi ve çevresel sürdürülebilirlik gibi farklı disiplinlerde geniş ve etkili kullanım alanları oluşturmuştur.

Bununla birlikte, transgenik hayvanların uygulama alanlarının giderek genişlemesi etik, ekolojik ve düzenleyici boyutların kapsamlı bir biçimde yeniden ele alınmasını gerektiren çok yönlü tartışmaları da gündeme getirmektedir (Wray-Cahen ve ark., 2022).

TRANSGENİK HAYVAN ELDE ETME YÖNTEMLERİ

Transgenik hayvan üretiminde uygulanan yöntemler, genetik materyalin embriyonik yapılara aktarılma stratejisine, hedeflenen genetik modifikasyonun doğruluğuna ve türler arası biyolojik farklılıklara bağlı olarak çeşitlilik göstermektedir. Bu teknikler, temel olarak genin doğrudan zigota enjekte edilmesine, embriyonik kök hücrelerin genetik olarak düzenlenmesine veya viral vektörlerin entegrasyon kapasitesinden yararlanılmasına dayanmakta olup, her biri kendine özgü avantajlar, verimlilik düzeyleri ve deneysel sınırlılıklar ortaya koymaktadır.

DNA Mikroenjeksiyonu

DNA mikroenjeksiyonu, transgenik hayvan üretiminde kullanılan en eski ve en yaygın yöntemlerden biri olup, hedef genin döllenmiş yumurtanın pronükleusuna doğrudan enjekte

edilmesine dayanır (Shakweer ve ark., 2023). Bu yöntem, ilk transgenik farelerin geliştirilmesinde temel teknik olarak kullanılmış ve özellikle memeli türlerinde yüksek uygulanabilirliği sayesinde standart bir transgenez aracı hâline gelmiştir (Park, 2023).

Mikroenjeksiyonun avantajı, eksojen DNA'nın embriyo gelişimini fazla etkilemeden genom içine entegre olabilmesidir. Ancak entegrasyonun rastlantısal olması, transgen ekspresyon seviyelerinde değişkenliğe yol açabileceğinden yöntemin önemli sınırlılıklarından biri olarak değerlendirilmektedir. Buna karşın, tek hücreli zigot aşamasında uygulanabilirliği ve laboratuvar koşullarında nispeten kolay uyarlanabilir olması, yöntemi birçok tür için hâlâ değerli kılmaktadır (Delerue ve Ittner, 2017).

Embriyonik Kök Hücre (ESC) Aracılı Gen Transferi

Embriyonik kök hücre teknolojisi, genetik modifikasyon sürecine daha yüksek hassasiyet kazandıran bir diğer yöntemdir. Bu yaklaşımda önce embriyonik kök hücreler kültürde büyütülür ve hedef gen, homolog rekombinasyon veya modern gen düzenleme teknikleri kullanılarak bu hücrelere aktarılır. Genetik olarak düzenlenmiş kök hücreler daha sonra blastosist aşamasındaki embriyolara enjekte edilir ve gelişimlerine rahim içerisinde devam etmeleri sağlanır (Popova ve ark., 2023).

Bu teknik sonucunda embriyonun hem modifiye edilmiş hem de edilmemiş hücre hatlarını birlikte taşıdığı kimerik hayvanlar elde edilir. Uygun eşleştirmelerle kimerik bireylerden tam transgenik yavrular üretilebilmesi yöntemin en önemli avantajıdır. ESC aracılı gen transferi, özellikle farelerde yaygın olarak kullanılmış ve hedefli gen silme (knock-out) veya gen ekleme (knock-in) çalışmalarında temel araç hâline gelmiştir (Ozawa ve ark., 2022).

Retrovirüs Aracılı Gen Transferi

Retroviral vektörler, transgenik hayvan üretiminde kullanılan etkili gen transfer araçları arasında yer almaktadır. Retrovirüslerin genomlarını konak hücre DNA'sına kalıcı olarak entegre edebilme kapasitesi, hedef genin embriyo genomuna yüksek verimlilikle aktarılmasını mümkün kılar. Bu yöntem özellikle sekiz hücreli embriyo aşamasında uygulandığında başarılı sonuçlar vermekte, yüksek aktarım oranları ve stabil gen ekspresyonu sağlayabilmektedir (Hallerman ve ark., 2023).

Retroviral gen transferinin önemli avantajları arasında yüksek enfeksiyon etkinliği ve çoklu hücrelere aynı anda gen aktarımı yer alır. Bununla birlikte, taşınabilecek gen boyutunun sınırlı olması ve retroviral entegrasyonun mutagenez riskini artırabilmesi, yöntemin dikkatle uygulanmasını gerektiren yönleridir. Buna rağmen, özellikle küçük genlerin aktarımında hızlı ve maliyet açısından uygun bir seçenek sunmaktadır.

TRANSGENİK UYGULAMALARIN TÜR BAZINDA DEĞERLENDİRİLMESİ

Transgenik teknolojiler farklı hayvan türlerinde değişen verimlilik, biyolojik yanıtlar ve uygulama hedefleri doğrultusunda özgün sonuçlar ortaya koymaktadır. Sığır, koyun, keçi ve domuz gibi çiftlik hayvanlarında genetik modifikasyonlar çoğunlukla biyofarmasötik üretim, hastalık direnci, gelişmiş verim özellikleri ve biyomedikal araştırma modelleri oluşturma amacıyla gerçekleştirilmektedir. Bu doğrultuda, her türün üreme biyolojisi, embriyo gelişim dinamikleri ve gen transferine yanıtı dikkate alınarak tür-spesifik stratejiler ve optimizasyonlar geliştirilmiştir. Aşağıda başlıca transgenik çiftlik hayvanları türlerinin genetik modifikasyon süreçleri ve uygulama alanları ele alınmaktadır.

Transgenik İnek

Rosie, 1997'de geliştirilen ilk terapötik protein üreten transgenik inektir. Genomuna yerleştirilen insan t-PA (tissue plasminogen activator) geni sayesinde kalp krizi ve felç tedavisinde kullanılan kan pıhtısı çözücü proteini sütünde üretebiliyordu (Wray-Cahen ve ark., 2022).

Bir inek, ilaç fabrikası gibi kullanılabilir fikri bu çalışmayla ilk kez somutlaşmıştır. Rosie'nin doğumu, memeli genomunun hassas manipülasyonunun mümkün olduğunu göstererek sonraki yıllarda insülin, lizozim, laktoferrin gibi insan proteinlerini üreten transgenik hayvan çalışmalarının önünü açmıştır (Wang ve ark., 2022). Özellikle lizostafin transgenik hatlarda mastitisin belirgin şekilde azaldığı ve β-laktoglobulin geninin silinmesiyle hipoalerjenik süt üretimi sağlanabilmektedir (Popova ve ark., 2023).

Transgenik Keçi

Transgenik keçilerde süt içinde kan pıhtılarını çözmede kullanılan LAtPA proteini üretilmiştir. Bu amaçla LAtPA genini taşıyan yapı, uygun promotörlerle birleştirilerek erken embriyolara enjekte edilmiş ve embriyolar taşıyıcı dişilere aktarılmıştır. İşlemler sonucunda transgeni taşıyan yavrular doğmuştur. Bu keçilerin sütünde LAtPA miktarı bazı örneklerde litre başına birkaç miligram seviyesinde kalmış, bazı örneklerde ise litre başına birkaç grama ulaşmıştır. Bu sonuçlar, süt keçilerinin terapötik protein üretimi için ekonomik bir biyoreaktör olarak kullanılabileceğini göstermektedir (Popova ve ark., 2023).

ATryn®, transgenik keçilerin sütünde üretilen rekombinant insan antitrombinidir ve kalıtsal antitrombin eksikliği olan hastalarda pıhtılaşma riskini azaltmak için kullanılır. Bu ürün, transgenik biyoreaktör hayvanlardan elde edilen ilk onaylı terapötik proteindir (Moura ve ark., 2011).

Transgenik Koyun

İlk başarılı transgenik koyunlar 1988'de üretilmiş ve β-laktoglobulin promotörü altına yerleştirilmiş insan faktör IX geni bu koyunların sütünde üretilmiştir. Ayrıca transgenin yavrulara da aktarılmış olduğu belirlenmiştir (Schnieke ve ark., 1997).

1991'da yapılan bir diğer çalışmada insan alfa-1 antitripsin (hA1AT) genini taşıyan beş transgenik koyun elde edilmiş, bu koyunlardan birinin sütünde litre başına 35 grama ulaşan hA1AT üretimi sağlanmış ve saflaştırılan proteinin doğal insan antitripsiniyle aynı biyolojik aktivite gösterdiği doğrulanmıştır (Wright ve ark., 1991).

Bunun yanında, keratin sentezinde görevli SAT ve OAS gibi genler aktarılmış ve bu genleri taşıyan transgenik koyunlar başarıyla üretilmiştir. Böylece genetik mühendisliğiyle yün veriminin artırılmasının mümkün olduğu ortaya konmuştur (Damak ve ark., 1996).

Transgenik Balık

Transgenik balık üretimine yönelik çalışmalar 1985 yılında başlamıştır (Lal ve ark., 2024).

Mikroenjeksiyon tekniği sazan, yayın, japon balığı, medaka, somon, tilapia, alabalık ve zebra balığı gibi birçok türde başarıyla uygulanmıştır (Wang ve ark., 2021).

Çoğu balık türünde pronükleuslar mikroskop altında net görülmediği için DNA doğrudan sitoplazmaya enjekte edilmiştir. Bu da hayatta kalma oranını artırmıştır (Houdebine and Chourrout, 1991).

Balıklarda döllenmenin vücut dışında gerçekleşmesi ve embriyoların doğrudan gelişebilmesi, memelilerde olduğu gibi koruyucu annelere transfer gereksinimini ortadan kaldırmıştır.

Transgenik balıklara aktarılan insan büyüme hormonu, japon balığı, gökkuşağı alabalığı ve somonda büyüme hızını yaklaşık iki kat artırmıştır (Rasal ve ark., 2024).

HAYVANSAL ÜRÜNLERİN BESİN DEĞERİNİN ARTIRILMASI

Transgenik hayvanlardan elde edilen ürünlerin biyofortifikasyonu fonksiyonel gıda üretiminde önemli fırsatlar sunar. Omega-3 yağ asitlerinden zenginleştirilmiş domuzlar, yağ asidi profili geliştirilmiş sığırlar ve düşük kolesterollü et/süt ürünleri bu kapsamda değerlendirilebilir (Jones & Wilson, 2022).

Besin değeri artırılmış transgenik ürünler, yalnızca insan sağlığını desteklemekle kalmaz aynı zamanda hayvanların büyüme performansını, bağışıklık etkinliğini ve yem değerlendirme kapasitesini de yükseltir (Bogdanovich ve ark., 2021). Böylece hem ekonomik hem de sağlık açısından çift yönlü bir fayda ortaya çıkar.

Süt bileşenlerinin transgenik yöntemlerle modifiye edilmesi hem hayvan sağlığını hem de insan beslenmesini doğrudan etkileyen önemli bir uygulama alanıdır. Laktasyona özgü promotörler sayesinde süt bezlerinde yüksek miktarda rekombinant protein sentezi mümkün hâle gelmiştir (Shakweer ve ark., 2023).

Transgenik hayvanların sütünde insan alfa-laktalbümini, lizozim, laktoferrin, IgF-I ve lizostafin gibi biyoaktif proteinlerin üretilebilmesi hem gıda endüstrisi hem de farmasötik alan için kritik bir yenilik sunmaktadır. Özellikle lizostafin salgılayan hatların mastitis riskini azalttığı gösterilmiştir (Wang ve ark., 2022).

Hipoalerjenik süt üretimi amacıyla β-laktoglobulin geninin silinmesi veya düzenlenmesi, süt alerjisi bulunan bireyler için daha güvenli ürünlerin geliştirilmesini sağlamaktadır (Popova ve ark., 2023). Ayrıca gen düzenleme çalışmaları, özellikle düşük verimli tropikal sığır ırklarının süt kalitesi ve miktarının yükseltilmesinde önemli bir potansiyel taşır (Johnsson, 2023).

ÇEVRESEL SÜRDÜRÜLEBİLİRLİK VE EKOSİSTEM YÖNETİMİ

Transgenik yaklaşımlar çevresel sürdürülebilirlik açısından önemli avantajlar sunmaktadır. Örneğin, fosfor sindirim kapasitesi artırılmış fitaz transgenik domuzlarda dışkıdaki fosfor miktarının %75'e kadar azalması, tarımsal akışla su kaynaklarına taşınan fosfor yükünü önemli ölçüde düşürmektedir. Aşırı fosfor birikimi göl, akarsu ve rezervuarlarda ötrofikasyona yol açtığından, bu azalmanın sağlanması içme suyu kalitesinin korunması, alg patlamalarının önlenmesi ve su ekosistemlerinin sürdürülebilirliğinin desteklenmesi açısından kritik önem taşımaktadır (Wray-Cahen ve ark., 2022).

Ayrıca yemden yararlanma oranı artırılmış, daha az atık üreten veya daha hızlı büyüyen hayvan hatlarının geliştirilmesi, tarımsal üretimin karbon ayak izini azaltma potansiyeline sahiptir. Gen düzenleme yoluyla metabolik verimliliğin artırılması, özellikle ruminant üretiminde sürdürülebilirlik açısından umut vericidir (Park, 2023).

BÜYÜME VE KARKAS KOMPOZİSYONUNDAKİ DEĞİŞİKLİKLER

Büyüme hormonu (GH), IgF-I ve yağ metabolizmasıyla ilişkili genlerin modifikasyonu, büyüme hızı ve karkas kompozisyonunda önemli iyileşmeler sağlamıştır. GH-modifiye edilmiş balıkların normal ağırlığın 5-11 katına ulaşabildiği rapor edilmiştir (Hallerman ve ark., 2023).

Myostatin (MSTN) geninin hedefli mutasyonu ile "çift kaslılık" fenotipine sahip koyun ve sığırlar elde edilmiştir. Bu tür gen modifikasyonlarının yüksek kas oranı sağladığı; ancak

doğum güçlüğü gibi sorunlar nedeniyle dikkatli şekilde uygulanması gerektiği vurgulanmaktadır. Ayrıca PPARγ geninin hedefli düzenlenmesiyle yağ dağılımı kontrol edilerek daha sağlıklı karkas yapıları geliştirilebilmektedir (Ge ve ark., 2021).

HASTALIKLARA DİRENÇLİ HATLARIN GELİŞTİRİLMESİ

Hastalıklara dirençli transgenik hatların geliştirilmesi, hayvan refahının en güçlü biyoteknolojik katkılarından biridir. Mastitise dirençli lizostafin transgenik inekler, enfeksiyon riskini önemli ölçüde azaltmaktadır (Wang ve ark., 2022).

Sivrisineklerde üremeyi engelleyen veya hastalık vektörlüğünü azaltan gen düzenleme uygulamaları ise zika, dang ve sıtma gibi hastalıklarla mücadelede büyük başarı göstermiştir (Park, 2023).

Model hayvanlarda gen düzenleme kullanılarak hipertansiyon, epilepsi veya davranış bozukluklarını modelleyen hatlar geliştirilmiştir (Ryazanova ve ark., 2023). Bu modeller hem biyomedikal araştırmalar hem de tedavi stratejilerinin geliştirilmesi açısından büyük önem taşır (Neff, 2021).

ENDÜSTRİYEL PROTEİN VE LİF ÜRETİMİ

Hayvanların biyoreaktör olarak kullanılması, düşük maliyetli farmasötik üretime olanak tanıyan yenilikçi bir yaklaşımdır. Transgenik keçilerden elde edilen ATryn® (antitrombin), klinik kullanım onayı alan ilk hayvansal rekombinant protein olup önemli bir dönüm noktasıdır (Popova ve ark., 2023).

Ayrıca örümcek ipeği proteinini üreten transgenik keçiler, balistik malzemeler ve biyomedikal ürünler için yüksek dayanımlı liflerin ekonomik biçimde üretilmesini sağlamıştır. Tavuk yumurtasında terapötik protein üretimi ise yüksek biyoverim ve düşük maliyet nedeniyle giderek daha fazla dikkat çekmektedir (Kim ve ark., 2021).

KSENOTRANSPLANTASYON VE TIBBİ UYGULAMALAR

Organ nakli ihtiyacının artması, ksenotransplantasyonu geleceğin önemli çözümlerinden biri hâline getirmiştir. CRISPR teknolojisiyle immünojenik domuz genlerinin silinmesi, insan proteinlerini kodlayan genlerin eklenmesi, PERV elementlerinin inaktive edilmesi gibi adımlarla reddin azaltılması konusunda büyük başarılar sağlanmaktadır (Wray-Cahen ve ark., 2022).

Domuz organlarının insan fizyolojisiyle boyutsal ve fonksiyonel olarak yakın olması, bu türü ksenotransplantasyon için ideal hâle getirmektedir (Popova ve ark., 2023).

GENETİK HASTALIK MODELLERİ VE ARAŞTIRMA UYGULAMALARI

Transgenik fareler, Cre/loxP sistemleri sayesinde dokuya veya zamana özgü gen modifikasyonlarının yapılabilmesine olanak tanımakta; bu da nörodejeneratif hastalıklar ve metabolik bozuklukların araştırılmasında büyük avantaj sunmaktadır (Johnsson, 2023).

Öte yandan sıçanlarda davranışsal ve nörolojik bozukluklar için geliştirilen modeller, translasyonel tıp açısından önemli bir kaynak oluşturmaktadır (Neff, 2021; Ryazanova ve ark., 2023).

TRANSGENİK HAYVAN ÜRETİMİNDE YENİ NESİL YAKLAŞIMLAR

Son yıllarda transgenik hayvan üretiminde kullanılan klasik teknikler yerini daha yüksek özgüllük, hassasiyet ve güvenlik sağlayan hedefli genom düzenleme teknolojilerine bırakmıştır. Özellikle CRISPR-Cas9, CRISPR-Cas12a (Khan ve Sallard, 2023), baz editörleri ve prime editing sistemleri, genetik modifikasyonun doğruluğunu artırarak off-target etkilerini önemli ölçüde azaltmış ve transgenik hatların daha kararlı biçimde elde edilmesine olanak sağlamıştır (Chen, 2023).

Prime editing, DNA çift zincir kırığı oluşturmaksızın spesifik nokta mutasyonları veya küçük ekleme/silmelerin yapılabilmesi nedeniyle embriyonik letalite, mozaiklik ve genom bütünlüğüne yönelik potansiyel riskleri azaltan yenilikçi bir araç olarak değerlendirilmektedir (Zhao ve ark., 2023). Bu teknolojik gelişmeler, özellikle büyük çiftlik hayvanlarında genom düzenleme verimliliğini artırarak biyoteknolojik uygulamaların ölçeklenebilirliğini güçlendirmiştir.

Buna ek olarak, in vitro gametogenez, organ-on-chip platformları ve yapay embriyonik mikroçevrelerin geliştirilmesi, transgenik hayvan üretiminde etik endişeleri azaltabilecek alternatif biyoteknolojik çözümler sunmaktadır. Bu yaklaşımlar hem deneysel hayvan kullanımını azaltmakta hem de modellerin fizyolojik doğruluğunu artırmaktadır (Botigelli ve ark., 2023; Goszczynski ve ark., 2023).

EPİGENETİK DÜZENLEME VE FENOTİP KARARLILIĞI

Transgenik hayvan üretiminde yalnızca gen dizisinin modifikasyonu değil, epigenetik mekanizmaların kontrolü de fenotipin kararlılığı ve kalıtımsal aktarımı açısından kritik önem taşımaktadır. DNA metilasyonu, histon modifikasyonları ve kromatin yeniden şekillenmesi, transgenlerin ekspresyon düzeylerini doğrudan etkileyerek istenen fenotipin sürdürülebilirliğini belirlemektedir.

Somatik hücre çekirdek transferi (SCNT) ile üretilen transgenik hayvanlarda epigenetik yeniden programlamanın yetersizliği; düşük yaşama oranı, gelişimsel anomaliler ve erken embriyonik kayıplar gibi sorunlara yol açmaktadır (Liao ve ark., 2024). Bu nedenle HDAC inhibitörleri ve H3K9me düzenleyicileri gibi epigenom modülatörlerinin kullanımı, klonlama verimini ve gelişimsel başarıyı artıran tamamlayıcı stratejiler olarak önerilmektedir (Matoba ve ark., 2024).

TRANSKRİPTOMİK VE PROTEOMİK YAKLAŞIMLARIN ENTEGRASYONU

Yeni nesil transgenik hayvan çalışmalarında, hedef genin modifikasyonu tek başına yeterli görülmemekte genom genelinde meydana gelen transkriptomik ve proteomik değişikliklerin bütüncül olarak değerlendirilmesi giderek daha fazla önem kazanmaktadır. RNA-seq ve tek hücreli transkriptomik analizler, genom düzenlemesinin hücre tipine özgü etkilerini ortaya koymakta ve istenmeyen biyolojik sapmaların erken aşamada tespit edilmesini sağlamaktadır (Wadood ve ark., 2025).

Proteomik analizler ise süt, yumurta veya kan gibi biyolojik sıvılarda üretilen rekombinant proteinlerin biyoaktivite, glikozilasyon profili, stabilite özellikleri ve potansiyel immünojenisite risklerinin değerlendirilmesinde önemli bir rol oynamaktadır. Bu yönüyle proteomik veriler, transgenik ürünlerin biyoteknolojik ve tıbbi kullanım alanlarına yönelik güvenilirlik değerlendirmelerinde kritik bir bileşen oluşturur (Guan ve ark., 2022).

HAYVAN REFAHI VE ETİK DEĞERLENDİRME

Transgenik hayvanların geliştirilmesinde hayvan refahı ve etik değerlendirmeler, araştırma süreçlerinin ayrılmaz bir parçası haline gelmiştir. Genetik modifikasyonların neden olabileceği fenotipik aşırılıklar, metabolik yüklenme, doğum güçlükleri veya bağışıklık sisteminin baskılanması gibi olası olumsuz etkiler, etik inceleme süreçlerinde merkeze alınmaktadır.

Bu kapsamda "Responsible Research and Innovation (RRI)" yaklaşımı; şeffaflık, paydaş katılımı ve risk-fayda analizini içeren bütüncül bir çerçeve sunmaktadır. Avrupa Birliği ve OECD, genom düzenlenmiş hayvanların değerlendirilmesinde mevcut GMO politikalarının güncellenmesini ve daha esnek, risk odaklı düzenlemelerin benimsenmesini önermektedir (Wray-Cahen ve ark., 2024).

KÜRESEL DÜZENLEYİCİ YAKLAŞIMLAR VE GELECEK POLİTİKALARI

Dünya genelinde transgenik ve genom düzenlenmiş hayvanlara yönelik düzenleyici yaklaşımlar önemli farklılıklar göstermektedir. ABD ve Brezilya gibi ülkeler hedefli mutasyon içeren genom düzenlenmiş hayvanları klasik GMO'lardan ayrı bir kategori olarak değerlendirirken, Avrupa Birliği daha temkinli ve süreç odaklı bir yaklaşım sürdürmektedir (Wray-Cahen ve ark., 2024).

Gelecekte ürün-temelli (product-based) düzenleyici çerçevelerin yaygınlaşması, genom düzenleme teknolojilerinin ticarileşmesi ve uluslararası standartların uyumlaştırılması beklenmektedir. Bu dönüşüm, özellikle tarımsal biyoteknolojide genom düzenlenmiş hayvanların daha hızlı şekilde uygulama alanı bulmasına zemin hazırlayacaktır.

TRANSGENİK TEKNOLOJİLERİN SINIRLARI, RİSKLERİ VE TARTIŞMALAR

Transgenik hayvan üretimindeki teknik zorluklar arasında rastgele genom entegrasyonu, mozaikçilik, çoklu kopya etkisi, epigenetik belirsizlikler, embriyonik kayıplar sayılabilir. Bu sorunlar, özellikle büyükbaş ve küçükbaş hayvanlarda verimliliği sınırlayabilmektedir (Park, 2023).

Ekolojik riskler arasında transgenik balıkların doğaya kaçması ve gen akışının ekosistem dengesini bozması yer alır (Hallerman ve ark., 2023). Etik tartışmalar ise hayvan refahı, gıda güvenliği ve genetiği değiştirilmiş organizmaların toplum tarafından kabulü gibi başlıklarda yoğunlaşmaktadır (Wray-Cahen ve ark., 2022).

SONUÇ

Transgenik hayvan biyoteknolojisi, modern moleküler tekniklerin hızla gelişmesiyle birlikte günümüzde tarım, hayvancılık, tıp, endüstri ve çevresel yönetim gibi birbirinden farklı disiplinlerde stratejik bir araç haline gelmiştir. Mikroenjeksiyon, embriyonik kök hücre manipülasyonu, viral vektörler, SCNT ve özellikle CRISPR-Cas sistemleri gibi yöntemler hassas gen düzenleme kapasitesini artırarak çok çeşitli türlerde kararlı, fonksiyonel ve uygulamaya dönük transgenik hatların geliştirilmesini mümkün kılmıştır. Bu sayede hipoalerjenik, yüksek besin değerine sahip veya terapötik protein içeren hayvansal ürünlerin elde edilmesi, büyüme performansı ve yemden yararlanmanın iyileştirilmesi, hastalıklara dirençli hatların geliştirilmesi ve endüstriyel protein/lif üretiminde ölçeklenebilir platformların oluşturulması önemli ölçüde kolaylaşmıştır.

Transgenik yaklaşımlar, yalnızca üretim verimliliğini artırmakla kalmayıp aynı zamanda çevresel sürdürülebilirliği destekleyen çözümler sunmaktadır. Atık yükünü azaltan metabolik modifikasyonlar, aquakültürde daha düşük yem girdisi ile yüksek büyüme performansı sağlayan hatlar ve sucul ekosistemleri tehdit eden fosfor kirliliğini azaltan transgenik domuz örnekleri, biyoteknolojinin çevresel faydalarını somutlaştırmaktadır. Bununla birlikte, domuz organlarının genetik olarak insanlaştırılması yoluyla ksenotransplantasyonda elde edilen başarılar, transgenik hayvanların tıbbi uygulamalardaki potansiyelinin çok daha geniş bir alanı kapsayacağını göstermektedir.

Güncel gelişmeler, klasik transgenik yöntemlerin yerini giderek hedefli gen düzenleme tekniklerine bırakmakta olduğunu açıkça ortaya koymaktadır. CRISPR-Cas9, Cas12a, baz editörleri ve prime editing gibi sistemler, gen düzenleme doğruluğunu artırarak mozaiklik, off-target etkiler ve gelişimsel kayıplar gibi teknik sorunları önemli ölçüde azaltma potansiyeli taşımaktadır. Aynı zamanda epigenetik düzenleme, single-cell transkriptomik, proteomik analizler ve in vitro gametogenez gibi tamamlayıcı teknolojiler, transgenik hatların biyolojik stabilitesinin ve güvenilirliğinin değerlendirilmesinde yeni bir dönemi başlatmıştır.

Bununla birlikte, transgenik hayvan biyoteknolojisinin sunduğu bu geniş olanaklar etik ve ekolojik tartışmaları da beraberinde getirmektedir. Hayvan refahı, biyogüvenlik, gen akışı, ekosistem riskleri ve toplumun teknolojiye yönelik algısı, araştırma ve uygulama süreçlerinde dikkatle yönetilmesi gereken temel başlıklardır. Ayrıca, ülkeler arasında farklılık gösteren düzenleyici politikalar, genom düzenlenmiş hayvanların ticarileşmesini ve uluslararası standartların oluşturulmasını doğrudan etkilemektedir.

Genel olarak değerlendirildiğinde, transgenik hayvan biyoteknolojisi hem temel bilimler hem de uygulamalı biyoteknoloji açısından büyük bir dönüşüm potansiyeli taşımaktadır. Ancak bu potansiyelin sürdürülebilir ve güvenli bir biçimde hayata geçirilebilmesinin yolu, etik prensiplerin gözetilmesi, çevresel risklerin titizlikle yönetilmesi, bilimsel şeffaflığın artırılması ve düzenleyici çerçevelerin bilimsel gelişmelere uyumlu şekilde güncellenmesinden geçmektedir.

Bu koşullar sağlandığında, transgenik hayvanlar geleceğin gıda üretiminden kişiselleştirilmiş tıbba, ekosistem yönetiminden yüksek verimli biyofabrikasyon sistemlerine kadar çok geniş bir alanda yenilikçi çözümler sunmaya devam edecektir.

KAYNAKÇA

Bogdanovich, D. M., Radchikov, V. F., Kuznetsova, V. N., Petrushko, E. V., Spivak, M. E., Sivko, A. N. (2021) IOP Conf. Ser., Earth Environ Sci, 848 012080. https://doi.org/10.1088/1755-1315/848/1/012080

Botigelli, R. C., Guiltinan, C., Arcanjo, R. B., Denicol, A. C. (2023) In vitro gametogenesis from embryonic stem cells in livestock species: recent advances, opportunities and challenges to overcome. Journal of Animal Science, 101, 1-9. https://doi.org/10.1093/jas/skad137

Chen, P. J., Liu, D. R. (2023) Prime editing for precise and highly versatile genome manipulation. Nat Rev Genet, 24(3), 161–177. https://doi.org/10.1038/s41576-022-00541-1

Damak, S., Su, H., Jay, N. P., Bullock, D. W. (1996) Improved wool production in transgenic sheep expressing insulin-like growth factor 1. Biotechnology (N Y), 185, 8. https://doi.org/10.1038/nbt0296-185

Delerue F, Ittner LM. (2017) Generation of Genetically Modified Mice through the Microinjection of Oocytes. J Vis Exp, 124, 55765. https://doi.org/10.3791/55765

Ge, L., Kang, J.,Dong, X., Luan, D., Su, G., Li, G., Zhang, Y., Quan, F. (2021) Myostatin site-directed mutation and simultaneous PPARγ site-directed knockin in bovine genome. J Cell Physiol, 236, 2592-2605. https://doi.org/10.1002/jcp.30017
Goszczynski, D. E., Navarro, M., Mutto, A. A., Ross, P. J. (2023) Review: Embryonic stem cells as tools for in vitro gamete production in livestock. Animal, 17, 100828. https://doi.org/10.1016/j.animal.2023.100828
Guan, B., Zhang, Z., Chai, Y., Amantai, X., Chen, X., Cao, X., Yue, X. (2022) N-glycosylation of milk proteins: A review spanning 2010–2022. Trends in Food Science & Technology, 128, 1-21. https://doi.org/10.1016/j.tifs.2022.07.017
Hallerman, E. M., Dunham, R., Houston, R. D., Walton, M., Wargelius, A., Wray-Cahen, D. (2023) Towards production of genome-edited aquaculture species. Rev Aquac, 15, 404-408. https://doi.org/10.1111/raq.12739
Houdebine, L. M., Chourrout, D. (1991) Transgenesis in fish. Experientia, 47(9), 891-897. https://doi.org/10.1007/BF01929879
Johnsson, M. (2023) Genomics in animal breeding from the perspectives of matrices and molecules. Hereditas, 160, 20. https://doi.org/10.1186/s41065-023-00285-w
Jones, H. E., Wilson, P. B. (2022) Progress and opportunities through use of genomics in animal production. Trends in Genetics, 38, 12. https://doi.org/10.1016/j.tig.2022.06.014
Khan, S., Sallard, E. (2023) Current and Prospective Applications of CRISPR-Cas12a in Pluricellular Organisms. Molecular Biotechnology, 65, 196–205. https://doi.org/10.1007/s12033-022-00538-5
Kim, Y. M., Park, K. J., Park, J. S., Jung, K. M., Han, J. Y. (2021) In vivo enrichment of busulfan-resistant germ cells for efficient production of transgenic avian models. Scientific Reports, 11, 9127. https://doi.org/10.1038/s41598-021-88706-6
Lal, J., Vaishnav, A., Singh, S. K., Meena, D. K., Biswas, P., Mehta, N. K., Priyadarshin, M. B. (2024) Biotechnological innovation in fish breeding: from marker assisted selection to genetic modification. Discover Biotechnology, 1, 7. https://doi.org/10.1007/s44340-024-00007-6
Liao, Z., Zhang, J., Sun, S., Li, Y., Xu, Y., Li, C., Cao, J., Nie, Y., Niu, Z., Liu, J., Lu, F., Liu, Z., Sun, Q. (2024) Reprogramming mechanism dissection and trophoblast replacement application in monkey somatic cell nuclear transfer. Nature Communications, 15, 5. https://doi.org/10.1038/s41467-023-43985-7
Matoba, S., Shikata, D., Shirai, F., Tatebe, T., Hirose, M., Nakata, A., Watanabe, N., Hasegawa, A., Ito, A., Yoshida, M., Ogura, A. (2024) Reduction of H3K9 methylation by G9a inhibitors improves the development of mouse SCNT embryos. Stem Cell Reports, 19, 906-921. https://doi.org/10.1016/j.stemcr.2024.04.003
Moura, R. R., Melo, L. M., Freitas, V. J. F. (2011) Production of Recombinant Proteins in Milk of Transgenic and Non-transgenic Goats. Braz. Arch. Biol. Technol, 54(5), 927-938. https://doi.org/10.1590/S1516-89132011000500010
Neff, E. P. (2021) Rats on the rise. Lab Animal, 50(8), 205-208. https://doi.org/10.1038/s41684-021-00812-0
Ozawa, M., Taguchi, J., Katsuma, K., Ishikawa-Yamauchi, Y., Kikuchi, M., Sakamoto, R., Yamada, Y., Ikawa, M. (2022) Efficient simultaneous double DNA knock-in in murine embryonic stem cells by CRISPR/Cas9 ribonucleoprotein-mediated circular plasmid targeting for generating gene-manipulated mice. Sci Rep 12, 21558. https://doi.org/10.1038/s41598-022-26107-z
Park, T. S. (2023) Gene-editing techniques and their applications in livestock and beyond. Anim Biosci, 36(2), 333-338. https://doi.org/10.5713/ab.22.0383
Popova, J., Bets, V., Kozhevnikova, E. (2023) Perspectives in Genome-Editing Techniques for Livestock. Animals 13, 2580. https://doi.org/10.3390/ani13162580

Rasal, K. D., Kumar, P. V., Risha, S., Asgolkar, P., Harshavarthini, M., Acharya, A., Shinde, S., Dhere, S., Rasal, A., Sonwane, A., Brahmane, M., Sundaray, J. K., Nagpure, N. (2024) Genetic improvement and genomic resources of important cyprinid species: status and future perspectives for sustainable production. Front. Genet, 15, 1398084. https://doi.org/10.3389/fgene.2024.1398084

Ryazanova, M.A., Plekanchuk, V.S., Prokudina, O.I., Makovka, Y.V., Alekhina, T.A., Redina, O.E., Markel, A.L. (2023) Animal Models of Hypertension (ISIAH Rats), Catatonia (GC Rats) and Audiogenic Epilepsy (PM Rats) Developed by Breeding. Biomedicines, 11, 1814. https://doi.org/10.3390/biomedicines11071814

Schnieke, A. E., Kind, A. J., Ritchie, W. A., Mycock, K., Scott, A. R., Ritchie, M., Wilmut, I., Colman, A., Campbell, K. H. S. () Human Factor IX Transgenic Sheep Produced by Transfer of Nuclei from Transfected Fetal Fibroblasts. Science, 278(5346), 2130-2133. https://doi.org/10.1126/science.278.5346.2130

Shakweer, W. M. E., Krivoruchko, A. Y., Dessouki, M., Khattab, A. A. (2023) A review of transgenic animal techniques and their applications. Journal of Genetic Engineering and Biotechnology,21, 55. https://doi.org/10.1186/s43141-023-00502-z

Wadood, A. A., Bordbar, F., Zhang, X. (2025) Integrating omics approaches in livestock biotechnology: innovations in production and reproductive efficiency. Front Anim Sci, 6,1551244. https://doi.org/10.3389/fanim.2025.1551244

Wang, Y., Hamid, N., Jia, P. P., Pei, D. S. (2021) A comprehensive review on genetically modified fish: keytechniques, applications and future prospects. Reviews in Aquaculture, 13, 1635-1660. https://doi.org/10.1111/raq.12538

Wang, S., Qu, Z., Huang, Q., Zhang, J., Lin, S., Yang, Y., Meng, F., Li, J., Zhang, K. (2022) Application of Gene Editing Technology in Resistance Breeding of Livestock. Life, 12, 1070. https://doi.org/10.3390/life12071070

Wray-Cahen, D., Hallerman, E., Tizard, M. (2024) Global regulatory policies for animal biotechnology: overview, opportunities and challenges. Front Genome, Ed. 6:1467080. https://doi.org/10.3389/fgeed.2024.1467080

Wray-Cahen, D., Bodnar, A., Rexroad, C., Siewerdt, F., Kovich, D. (2022) Advancing genome editing to improve the sustainability and resiliency of animal agriculture. CABI Agriculture and Bioscience, 3, 21. https://doi.org/10.1186/s43170-022-00091-w

Wright, G., Carver, A., Cottom, D., Reeves, D., Scott, A., Simons, P., Wilmut, I., Garner, I., Colman, A. (1991) High Level Expression of Active Human Alpha-1-Antitrypsin in the Milk of Transgenic Sheep. Nat Biotechnol 9, 830-834. https://doi.org/10.1038/nbt0991-830

Zhao, Z., Shang, P., Mohanraju, P., Geijsen, N. (2023) Prime editing: advances and therapeutic applications. Trends in Biotechnology, 41, 8. https://doi.org/10.1016/j.tibtech.2023.03.004

THE BIODIESEL FUEL CHARACTERISTICS OF *BRASSICA RAPA* SSP. *OLEIFERA* L. PURE LINES

Assoc. Prof. Dr. Fatma KAYAÇETİN

Ankara University, Faculty of Agriculture, Department of Field Crops, Ankara, Türkiye

ABSTRACT

This study aimed to evaluate the biodiesel fuel properties of six turnip rape (*Brassica rapa* ssp. *oleifera* L.) pure lines bred and cultivated in Türkiye. The research was conducted under semi-arid climatic conditions in Ankara, with field trials carried out during the 2019-20 and 2020-21 autumn sowing seasons. The objective was to determine whether turnip rape pure lines can serve as a suitable raw material for high-quality biodiesel production. Six turnip rape pure lines of different regional origins in Türkiye were used in the study. Oils obtained from the seeds of the pure lines were analyzed according to ISO and TS EN standards to determine acid value, water content, iodine value, cold filter plugging point, flash point, as well as mono-, di-, and triglyceride and glycerol contents. Biodiesel production was performed via base catalyzed transesterification using methanol and sodium hydroxide, followed by reaction, separation, washing, and drying steps. Physicochemical properties of the resulting biodiesel samples were compared with the TS EN 14214 standard. The analyses indicated that biodiesel samples from all pure lines met the TS EN 14214 standard. Acid values ranged from 0.29 to 0.37 mg KOH g^{-1}, water content from 142.50 to 267.50 mg kg^{-1}, iodine values from 103.17 to 105.62 g iodine 100 g^{-1}, cold filter plugging points between −2.00 and −2.50 °C, and flash points between 175 and 186 °C. Levels of monoglycerides, diglycerides, triglycerides, and free glycerol were all below the standard limits, demonstrating high transesterification efficiency. Minor differences in fuel properties were determined among the lines. Turnip rape pure lines can be considered a suitable raw material source for high-quality biodiesel production under Türkiye conditions. The results indicate that these pure lines offer potential as an alternative oilseed crop for sustainable biofuel production.

Keywords: Turnip Rape, Biodiesel, Pure Line; TS EN 14214.

INTRODUCTION

Brassica rapa ssp. *oleifera* L. (turnip rape) is a prominent member of the *Brassicaceae* family and represents an important annual oilseed crop cultivated in various regions worldwide (Salehi et al., 2021; Bosi et al., 2022). In Türkiye, although this subspecies is not yet commercially cultivated for industrial oil or biodiesel production, wild forms naturally occur in the native flora, contributing to the country's plant genetic diversity (Al-Shehbaz et al., 2007; Kayaçetin, 2020). This natural variability provides a valuable resource for developing new cultivars adapted to different environments and capable of producing oils suitable for biodiesel applications (Kayaçetin, 2021; Rana et al., 2022).

The species is characterized by moderate to high oil content, typically ranging from 30% to 40%, with erucic acid representing a major fatty acid component (Kayaçetin et al., 2022; Kayaçetin et al., 2018). Erucic acid, a very long-chain monounsaturated fatty acid, is valued in non-food industrial sectors due to its hydrophobic nature and high oxidative stability, making

it suitable for biofuel production, lubricant formulations, and specialty polymer synthesis (Knutsen et al., 2016; Wendlinger et al., 2014). In turnip rape, erucic acid levels can reach up to 50% (Sharafi et al., 2015), while Kayaçetin (2023) reported values approaching 40%. Although such high erucic acid concentrations limit the suitability of turnip rape oil for human consumption (Poddar et al., 2021), they enhance its potential as a promising raw material for biodiesel production.

Previous studies on *Brassica* species have demonstrated that both genetic background and environmental conditions strongly influence plant vigor and final oil quality (Johnston et al., 2002; Shekhawat et al., 2012). Significant genotype × environment interactions have been reported for seed yield and key agronomic traits, emphasizing the importance of identifying well-adapted lines through multi-environment testing (Bocianowski et al., 2019; Kayaçetin, 2019). Moreover, the consistently high erucic acid content reported in turnip rape-with mean values exceeding 50% in some cases-further supports its suitability for industrial-grade oil and biodiesel production (Kayaçetin et al., 2018; Cartea et al., 2019; Konuskan et al., 2019).

Understanding the biodiesel-related characteristics of turnip rape is essential for fully assessing its potential as an alternative energy crop. Traits such as fatty acid composition, oxidative stability, cold flow properties, and glyceride profiles are integral in determining biodiesel quality and compliance with international fuel standards. However, limited information exists regarding the performance of turnip rape pure lines under different environmental conditions in Türkiye, particularly in terms of biodiesel fuel properties.

Therefore, the present study aimed to investigate the biodiesel-related fuel characteristics of six pure lines of turnip rape grown under the semi-arid conditions of Ankara, Türkiye. The findings provide critical insights for identifying high-performing, biodiesel-suitable lines that can support future breeding programs and industrial oil production.

MATERIALS AND METHODS

The experiment was conducted during the 2019-2020 and 2020-2021 autumn growing seasons at the experimental fields of the Field Crops Central Research Institute, located at an altitude of 1050 m. Monthly climatic data for the study area, including long-term averages and values recorded during the experimental seasons, are presented in Figure 1.

Based on the meteorological data for the growing seasons, the long-term average total precipitation was 391.9 mm, while 269.6 mm and 273.6 mm were recorded in 2019-2020 and 2020-2021, respectively. Long-term average temperature and relative humidity were 10.5 °C and 63.9%, while for the first and second experimental years, the corresponding values were 10.5 °C-58.3% and 12.0 °C-65.5% (Figure 1; Kayaçetin, 2023). The soil at the experimental site was clay-loam in texture, low in organic matter, and slightly alkaline (Kayaçetin and Aydin, 2024).

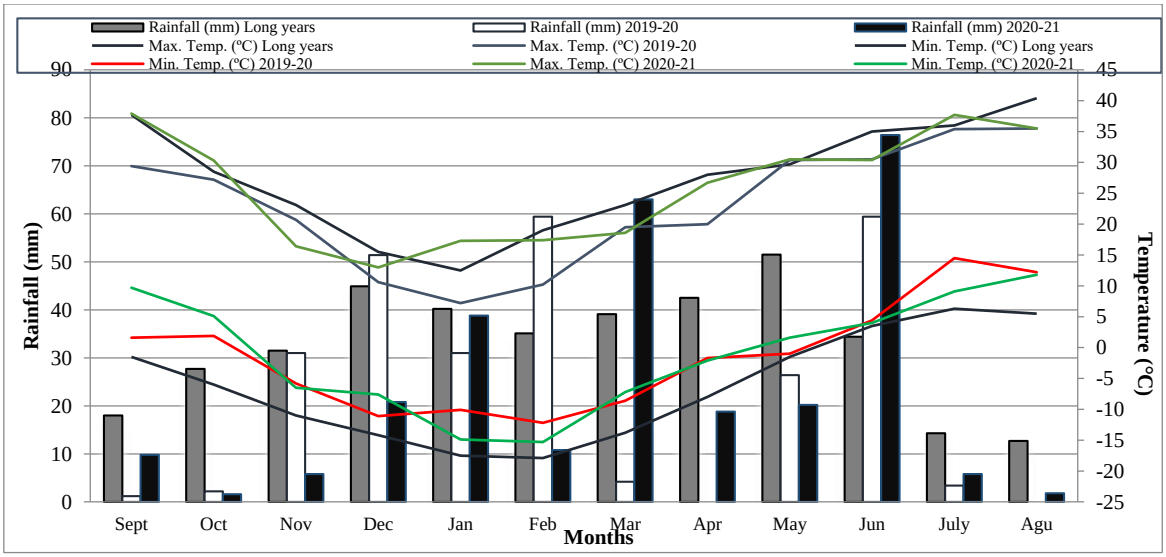


Figure 1. Monthly climatic data for the study area: long-term averages and 2019-2020 and 2020-2021 values

A total of six turnip rape pure lines were used in the study, originating from different regions of Türkiye: three lines from Tekirdağ, and one line each from Bursa, Tokat, and a line representing the genetic diversity of Türkiye. This selection provided a broad genetic base from multiple ecological regions. All pure lines were maintained and characterized at the Ankara Field Crops Central Research Institute and were developed using the Pure Line Selection Method. All turnip rape lines used in this study were strictly winter-type genotypes.

The experiment was conducted in a randomized complete block design with four replications, with seeds sown at 200 seeds m^{-2} and plots fertilized according to standard practices (Kinay and Kayaçetin, 2023).

Biodiesel production and analysis were carried out at the Biofuel Laboratory, DB Agricultural Energy, Izmir, Türkiye, using a laboratory-scale biodiesel processor. Seed oils from each pure line were extracted following ISO 734-1. Acid value, water content, and iodine value were determined according to TS EN 14104, EN ISO 12937, and TS EN 14111, respectively. Cold filter plugging point and flash point were measured following TS EN 116 and TS EN ISO 2719 standards. Mono-, di-, and triglycerides, as well as glycerol contents, were quantified using gas chromatography according to TS EN 14105 (Kayaçetin, 2023).

Biodiesel was synthesized via base-catalyzed transesterification using methanol and sodium hydroxide, as described by Kayaçetin (2023). The procedure involved four main stages: reaction, separation, washing, and drying. Briefly, 200 mL of oil from each genotype was mixed with methanol (20% v/v) containing 0.35 wt% NaOH, stirred, and heated at 60 °C for 1 h. After settling for 8 h, the biodiesel and glycerol layers were separated. The biodiesel layer was washed several times with warm distilled water at 55 °C, and residual methanol was removed by heating at 120 °C under continuous stirring to obtain purified biodiesel. This method ensured consistent biodiesel production suitable for evaluating fuel properties across the different turnip rape pure lines.

RESULTS AND DISCUSSION

The acid value, water content, iodine value, cold filter plugging point, flash point, and glyceride composition-including mono-, di-, triglycerides, and free and total glycerol-of biodiesel produced from turnip rape pure lines are presented in Table 1.

Table 1. Biodiesel Fuel Properties of Turnip Rape Pure Lines Compared with TS EN 14214 Standard Limits

Traits	Pure lines						Standard TS EN 14214	
	Tekirdağ1	Bursa	Tekirdağ2	Türkiye	Tokat	Tekirdağ3	Min-	Max
Acid value (mg KOH g^{-1})	0,37	0,29	0,36	0,36	0,36	0,34	-	0,50
Water content (mg kg^{-1})	142,50	197,50	157,50	235,00	267,50	260,00	-	500,00
Iodine value (g iodine 100 g^{-1})	103,17	104,35	104,98	105,21	103,35	105,62	-	120,00
Cold filter plugging point (°C)	-2,00	-2,00	-2,00	-2,00	-2,00	-2,50	−20	20
Flash point (°C)	182,50	183,00	185,00	175,00	180,00	186,00	120,00	-
Glyceride (%)								
Monoglyceride	0,27	0,30	0,27	0,27	0,24	0,30	-	0,80
Diglyceride	0,05	0,07	0,05	0,01	0,02	0,01	-	0,20
Triglyceride	0,01	0,02	0,02	0,01	0,02	0,01	-	0,20
Free glycerol	0,01	0,01	0,01	0,01	0,01	0,01	-	0,02
Total glycerol	0,09	0,10	0,09	0,09	0,08	0,10	-	0,25

Based on the two-year average data, biodiesel produced from the seed oils of the pure lines generally complies with the TS EN 14214 standard. Acid values ranged from 0.29 to 0.37 mg KOH g^{-1}, well below the maximum limit of 0.50 mg KOH g^{-1}, indicating high resistance to hydrolytic degradation and efficient esterification.

Water content varied between 142.50 and 267.50 mg kg^{-1}, considerably below the 500 mg kg^{-1} limit, reducing the risk of corrosion, microbial growth, or phase separation in fuel systems. These low moisture levels also confirm appropriate storage and processing conditions.

Iodine values ranged from 103.17 to 105.62 g iodine 100 g^{-1}, below the standard maximum of 120 g iodine 100 g^{-1}, indicating that the fatty acid composition does not compromise oxidative stability, which is advantageous for long-term storage.

Cold filter plugging points ranged from −2.00 to −2.50 °C, demonstrating that the biodiesel maintains sufficient flow properties in winter conditions typical of temperate climates. Flash points were between 175 and 186 °C, well above the minimum requirement of 120 °C, reflecting good storage safety and low flammability.

Glyceride analysis revealed very low levels of mono-, di-, and triglycerides, confirming the high efficiency of the transesterification reaction and indicating minimal risk of fuel quality problems such as soap formation, sedimentation, or injector clogging. Both free and total glycerol levels were well below standard limits, further confirming high biodiesel quality.

Chemical analysis of seed oils obtained from autumn-sown turnip rape pure lines indicates that they are suitable for biodiesel production in accordance with TS EN 14214 standards (Yesilyurt et al., 2019; Akhtar, 2022; Kayaçetin, 2023). The use of non-food oils as biodiesel feedstock is

a key strategy for sustainable fuel production (Aydın et al., 2024; Kayaçetin, 2023). Due to their high erucic acid content, these turnip rape pure lines are not suitable for human consumption; however, their fatty acid profiles and strong adaptability to Türkiye's agroclimatic conditions make them promising candidates for industrial biodiesel applications.

CONCLUSION

This study demonstrated that the pure lines of *Brassica rapa* ssp. *oleifera* possess physicochemical characteristics suitable for biodiesel production. All examined lines complied with TS EN 14214 standards in terms of acid value, water content, iodine value, flash point, and glyceride composition, indicating that oils derived from these genotypes can be effectively used to produce high-quality biodiesel. Minor differences were observed among the lines; but overall, all pure lines exhibited properties consistent with international biodiesel standards, confirming their suitability as a raw material for sustainable biofuel production under Türkiye's conditions.

The slight variations among the lines also highlight the potential for future breeding programs aimed at enhancing biodiesel quality. Collectively, these findings support the use of turnip rape pure lines cultivated in Türkiye as a promising alternative oilseed crop for sustainable, high-quality biodiesel production.

ACKNOWLEDGMENTS

This study includes part of the Ankara trials within the business plan of DB Tarımsal Enerji San. Tic. A.Ş. The author gratefully acknowledges TÜBİTAK (Project No. 1505-5190038), DB Tarımsal Enerji San. Tic. A.Ş. for biodiesel analyses, the Field Crops Central Research Institute for their support, and the project team for their contributions.

REFERENCES

Akhtar, F. (2024). Green catalysis revolution: The role of nanocatalysts in biodiesel production via transesterification. *Indian Journal of Natural Sciences, 15*(89).

Al-Shehbaz, I. A., Mutlu, B., & Dönmez, A. A. (2007). The Brassicaceae (Cruciferae) of Turkey, updated. *Turkish Journal of Botany, 31*(4), 327–336.

Aydın, F., Oğuz, H., Şahin, S., Öğüt, H., & Kayaçetin, F. (2024). Impact of turnip biodiesel–diesel blends on engine performance and fuel properties: A comparative analysis. *International Journal of Automotive Engineering and Technologies, 13*(4), 144–152.

Bosi, G., De Felice, S., Wilkinson, M. J., Allainguillaume, J., Arru, L., Nascimbene, J., & Buldrini, F. (2022). Brassica and *Sinapis* seeds in medieval archaeological sites: An example of multiproxy analysis for their identification and ethnobotanical interpretation. *Plants, 11*(16), 2100. https://doi.org/10.3390/plants11162100

Cartea, E., Haro-Bailón, D., Padilla, G., Obregón-Cano, S., Del Río-Celestino, M., & Ordás, A. (2019). Seed oil quality of *Brassica napus* and *Brassica rapa* germplasm from Northwestern Spain. *Foods, 8*(8), 292. https://doi.org/10.3390/foods8080292

Johnston, A. M., Tanaka, D. L., Miller, P. R., Brandt, S. A., Nielsen, D. C., Lafond, G. P., & Riveland, N. R. (2002). Oilseed crops for semiarid cropping systems in the northern Great Plains. *Agronomy Journal, 94*, 231–240. https://doi.org/10.2134/agronj2002.2310

Kayaçetin, F. (2019). Morphological characterization and relationships among some wild and domestic Turkish mustard genotypes. *Turkish Journal of Botany, 43*(4), 499–515. https://doi.org/10.3906/bot-1904-29

Kayaçetin, F. (2020). Performance of some important agronomic characteristics of *Brassica juncea* L. genotypes under fall sowing at two locations of Ankara, Turkey. *KSU Journal of Agriculture and Nature, 23*(4), 966–974.

Kayaçetin, F. (2021). Effect of environment on seed and oil yield of Turkish *Brassica rapa* L. genotypes. *Fresenius Environmental Bulletin, 30*(1), 60–69.

Kayaçetin, F. (2023). Comparison of some species in genus *Brassica* cultivated on clay-loamy soils under semi-arid agroecosystem for suitability to biodiesel production. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 45*(4), 11963–11980. https://doi.org/10.1080/15567036.2023.2176158

Kayaçetin, F., & Aydin, O. (2024). Growth and yield of local and exotic white, brown, and black mustard lines sown in the spring season in Turkey. *Communications in Soil Science and Plant Analysis, 55*(22), 3447–3456. https://doi.org/10.1080/00103624.2024.972341

Kayaçetin, F., Aydin, O., Unal, S., & Khawar, K. M. (2023). Determination of the growth and yield traits of some mustard species under semi-arid central Anatolian conditions. *Genetika, 55*(3), 829–840. https://doi.org/10.2298/GENSR2303829K

Kayaçetin, F., Efeoglu, B., & Sarioglu, G. (2018). Evaluation of fatty acid compositions of wild and domestic Turkish mustard genotypes. *International Journal of Secondary Metabolite, 5*(4), 270–278.

Kayaçetin, F., Khawar, H. M., Aydin, O., Kinay, A., & Sameeullah, M. (2022). *Gıda ve enerji endüstrisine uygun hardal çeşitlerinin geliştirilmesi* (TÜBİTAK-1505 Proje Sonuç Raporu).

Kinay, A., & Kayaçetin, F. (2023). Phenology, morphology, yield and quality characteristics of mustard species (*Brassica* spp.) suitable for energy sector. *Gesunde Pflanzen, 75*(5), 1953–1962. https://doi.org/10.1007/s10343-023-00856-9

Knutsen, H. K., Alexander, J., Barregåsa Lehird, L., Bignami, M., Brüschweiler, B., & Vleminckx, C. (2016). Erucic acid in feed and food. *EFSA Journal, 14*(11), e04593. https://doi.org/10.2903/j.efsa.2016.4593

Konuskan, D. B., Arslan, M., & Oksuz, A. (2019). Physicochemical properties of cold-pressed rapeseed, mustard and other oils. *Saudi Journal of Biological Sciences, 26*(2), 340–344. https://doi.org/10.1016/j.sjbs.2018.10.020

Poddar, K. H., Sikand, G., Kalra, D., Wong, N., & Duell, P. B. (2021). Mustard oil and cardiovascular health: Why the controversy? *Journal of Clinical Lipidology, 16*(1), 13–22. https://doi.org/10.1016/j.jacl.2021.11.002

Rana, Q. U. A., Irfan, M., Ahmed, S., Hasan, F., Shah, A. A., Khan, S., Rehman, F. U., Khan, H., Ju, M., Li, W., et al. (2022). Biocatalytic transesterification of mustard oil for biodiesel production. *Biofuels, 13*(1), 69–76. https://doi.org/10.1080/17597269.2019.1655907

Salehi, B., Quispe, C., Butnariu, M., Sarac, I., Marmouzi, I., Kamle, M., Tripathi, V., Kumar, P., Bouyahya, A., Capanoglu, E., et al. (2021). Phytotherapy and food applications from *Brassica* genus. *Phytotherapy Research, 35*, 3590–3609. https://doi.org/10.1002/ptr.7174

Sharafi, Y., Majidi, M. M., Goli, S. A. H., & Rashidi, F. (2015). Oil content and fatty acids composition in *Brassica* species. *International Journal of Food Properties, 18*(10), 2145–2154. https://doi.org/10.1080/10942912.2014.962048

Shekhawat, K., Rathore, S. S., Premi, O. P., Kandpal, B. K., & Chauhan, J. S. (2012). Advances in agronomic management of Indian mustard. *International Journal of Agronomy, 2012*, 1–14. https://doi.org/10.1155/2012/314842

Wendlinger, C., Hammann, S., & Vetter, W. (2014). Various concentrations of erucic acid in mustard oil and mustard. *Food Chemistry, 153*, 393–397. https://doi.org/10.1016/j.foodchem.2013.12.073

Yesilyurt, M., Arslan, M., & Eryilmaz, T. (2019). Application of response surface methodology for the optimization of biodiesel production from yellow mustard (*Sinapis alba* L.) seed oil. *International Journal of Green Energy, 16*(1), 60–71. https://doi.org/10.1080/15435075.2018.1532431

PHENOLOGY, MORPHOLOGY, AND SEED YIELD OF TURNIP RAPE PURE LINES

Assoc. Prof. Dr. Fatma KAYAÇETİN

Ankara University, Faculty of Agriculture, Department of Field Crops, Ankara, Türkiye

ABSTRACT

The environmental impacts of non-renewable fossil fuel consumption have increased the need for renewable and sustainable energy sources. *Brassica rapa* ssp. *oleifera* (turnip rape) is an economically important oilseed crop widely used in industrial oil production. This study aimed to evaluate the phenological, morphological, and seed yield characteristics of six pure lines of turnip rape under autumn sowing conditions in Ankara, Türkiye, during the 2019-2020 growing season. The study material consisted of six genetically distinct turnip rape pure lines originating from different regions of Türkiye. The experiment was conducted in a randomized complete block design with four replications. Phenological observations included days from sowing to emergence, days from emergence to the 4-6 leaf rosette stage, days to 50% flowering, days to 50% capsule formation, and days to harvest. Morphological and yield traits measured were plant height, number of lateral branches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight, and seed yield (kg/da). All pure lines exhibited similar phenological development, completing their growth cycle in approximately 281 days, indicating that phenology was primarily influenced by environmental conditions. Morphological traits such as plant height (141.40-156.35 cm) and number of lateral branches (5.50-6.75 branches/plant) showed limited variation. However, significant differences ($p < 0.01$) were observed among the lines for the number of capsules per plant (201.05-343.55), seeds per capsule (16.33-21.80), and seed yield (348.73-407.99 kg/da). Tekirdağ3 had the highest seed yield (407.99 kg/da) despite producing fewer capsules, demonstrating superior reproductive efficiency. Tokat produced the highest number of capsules but showed moderate seed yield due to fewer seeds per capsule. Bursa achieved relatively high yield owing to the highest seed set per capsule (21.80 seeds/capsule). Thousand seed weight varied minimally among the lines (1.87-2.03 g). Tekirdağ3 stands out as a promising pure line for improving seed yield in turnip rape due to its efficient reproductive strategy. Additionally, Tekirdağ1, Bursa, Tekirdağ2, and Tokat represent valuable genetic resources for breeding programs targeting increased capsule number and seed set. The results provide important insights for selecting high-performing genotypes adaptable to diverse environmental conditions.

Keywords: *Brassica rapa* ssp. *oleifera*, Seed Yield, Phenological-Morphological Traits, Genetic Variability.

INTRODUCTION

Brassica rapa ssp. oleifera (turnip rape) is an economically important annual oilseed crop and is used as a raw material in biodiesel production (Thomas et al., 2012; Aslan, 2023; Kayaçetin, 2023; Kinay and Kayaçetin, 2023; Nisar et al., 2018). Although turnip rape seeds are not currently produced in Türkiye for biodiesel purposes, wild forms of this species are naturally found within the country's genetic resources (Kayaçetin, 2020). Therefore, utilizing the genetic

diversity available in local turnip rape genotypes to develop new, high-yielding, low-cost, and biodiesel-suitable cultivars is of great importance (Kayaçetin, 2021; Rana et al., 2022).

Turnip rape seeds contain 30-40% oil, a substantial proportion of which consists of erucic acid (40-50%) (Kayaçetin et al., 2022; Kayaçetin et al., 2018). Due to its high erucic acid content, the oil is unsuitable for human consumption (Poddar et al., 2021), yet it offers significant potential for industrial applications. This highlights the importance of identifying appropriate lines and cultivars for industrial oil production (Kayaçetin, 2023; Kayaçetin et al., 2023).

Genotypic differences strongly influence adaptation to environmental conditions, leading to considerable variation in growth and yield performance (Nowosad et al., 2019; Kayaçetin, 2021). Studies conducted on mustard and other Brassica species demonstrate that genotype × environment interaction has a pronounced effect on morphological traits and yield components (Bocianowski et al., 2019). Evaluating multiple genotypes makes it possible to identify superior lines adapted to specific agroecological conditions (Kayaçetin, 2019). Furthermore, the high erucic acid content of turnip rape, reaching an average of approximately 50%, supports its suitability for industrial rather than nutritional use (Kayaçetin et al., 2018; Cartea et al., 2019; Konuşkan et al., 2019).

Both genetic and environmental factors significantly affect the performance of Brassica genotypes (Johnston et al., 2002; Shekhawat et al., 2012). Variations in yield and yield components among genotypes facilitate the selection of superior lines in breeding programs (Fayyaz and Afzal, 2014). Moreover, an ideal genotype is expected to exhibit both high mean performance and high stability across diverse environments (Kayaçetin, 2021).

In this study, the evaluation of phenological, morphological, and yield characteristics of turnip rape pure lines is considered essential for industrial oil production and future breeding programs. Accordingly, the present study aimed to assess the phenology, morphology, and seed yield of six turnip rape pure lines under the semi-arid climatic conditions of Ankara, Türkiye. The findings offer valuable insights for identifying high-performing lines suitable for diverse environmental conditions.

MATERIALS AND METHODS

Experimental Area, Climate, and Soil Characteristics

The experiment was carried out during the 2019-20 autumn growing season at the experi-mental fields of the Field Crops Central Research Institute, situated at an altitude of 1050 m. Monthly climatic data for the study site, including long-term averages and the values recorded during the experimental growing season, are presented in Table 1.

When comparing the long-term climatic averages with the 2019-20 growing season, notable differences in rainfall patterns were observed. According to the long-term data, the highest rainfall typically occurs in May (51.5 mm). However, during the 2019-20 season, rainfall distribution was irregular, with significant deviations from the long-term averages in De-cember, February, and June. Maximum temperatures in 2019-20 were generally lower than the long-term averages, particularly during the winter months (December-February). Mini-mum temperatures exhibited a similar pattern: although long-term averages were lower in January and February, the 2019-20 period recorded higher minimum temperatures, while in March and April, temperatures remained below the long-term averages. These observations indicate that the 2019-20 season experienced substantial deviations from typical climatic conditions, with extreme weather events particularly pronounced during winter and early spring.

Table 1. Monthly climatic data for the study area: long-term averages and 2019-20 values

Climatic Factors	Years/Months	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Rainfall (mm)	Long years	18	27.7	31.5	44.9	40.2	35.1	39.1	42.5	51.5	34.4	14.3	12.7
	2019-20	1.2	2.2	31.0	51.4	31.0	59.4	4.2	0.0	26.4	59.4	3.4	0.0
Max. Temp. (ºC)	Long years	37.7	28.5	23.1	15.5	12.5	19.0	23.1	28.0	29.7	35.0	36.0	40.4
	2019-20	29.4	27.2	20.7	10.6	7.2	10.2	19.5	20.0	30.4	30.5	35.4	35.5
Min. Temp. (ºC)	Long years	-1.5	-6.0	-11.0	-14.2	-17.5	-17.9	-13.8	-8.0	-1.5	3.5	6.3	5.5
	2019-20	1.6	1.9	-5.8	-11.1	-10.1	-12.2	-8.6	-1.7	-1.0	4.4	14.5	12.2

Soil analysis of the 0-20 cm layer revealed low organic matter content (1.97%), a slightly alkaline pH (7.7), high calcium carbonate concentration (30%), and a clay-loam texture (Kayaçetin and Aydin, 2024).

Experimental Material and Design

The study was conducted using six pure lines of turnip rape (*Brassica rapa* ssp. *oleifera*) originating from various regions of Türkiye, including three lines from Tekirdağ, and one line each from Bursa, Tokat, and a representative line encompassing the genetic diversity of Türkiye. This selection ensured a broad genetic base from multiple ecological zones. All pure lines were maintained and characterized at the Ankara Field Crops Central Research Institute and were developed through the Pure Line Selection Method. The lines used in this study were strictly winter-type genotypes.

The field experiment was laid out in a randomized complete block design with four replications. Sowing was performed at a rate of 200 seeds m^{-2} and a depth of 2-3 cm. Each experimental plot consisted of six rows spaced 30 cm apart, with a row length of 6 m, covering a total area of 10.8 m^2 per plot. Fertilization included applications of nitrogen, phosphorus, and sulfur at rates of 35, 50, and 100 kg ha^{-1}, respectively (Franzen and Lukack, 2007; Grant et al., 2007; Kayaçetin, 2023). Phosphorus and sulfur were applied before sowing, whereas nitrogen was split between the sowing date and the rosette stage.

Studied traits

During the 2019-20 growing season, phenological, morphological, and yield-related traits of the turnip rape (*Brassica rapa* ssp. *oleifera*) pure lines were systematically evaluated. Phenological observations included the number of days from sowing to emergence, the duration from emergence to the 4-6 leaf rosette stage, and the number of days from emergence to 50% flowering and 50% capsule formation. Morphological traits recorded were plant height (cm) and the number of lateral branches per plant, while yield-related traits included the number of capsules per plant, number of seeds per capsule, thousand seed weight (g), and seed yield (kg/ha) (Kayaçetin, 2019). All measurements were performed following standard procedures for turnip rape cultivation, with phenological stages recorded as days from sowing and emergence, and morphological and yield components measured at physiological maturity prior to harvest. To minimize border effects, all observations were conducted on plants located within the central rows of each plot.

Statistical Analysis

Morphological and yield data were analyzed using analysis of variance (ANOVA) in JMP statistical software. Mean differences among the lines were compared using the Least Significant Difference (LSD) test at the 1% probability level ($p < 0.01$) (Kalayci, 2005).

RESULTS AND DISCUSSION

The phenological observations presented in Table 2 show that the turnip rape (*Brassica rapa* ssp. *oleifera*) pure lines progressed through the same developmental stages at similar times under the given ecological conditions, with no differences detected among the lines. Sowing was carried out on 15 September 2019, and emergence occurred 26 days later, on 11 October 2019. The plants reached the 4-6 leaf rosette stage on 12 November 2019 and remained in a pronounced vegetative growth phase throughout the winter months.

With the improvement of spring conditions, generative development accelerated, with 50% flowering observed on 25 April 2020 and 50% capsule formation on 10 May 2020. Harvest took place on 27 June 2020, completing a total growing period of approximately 9.5 months. Based on the durations presented in the table, the period from sowing to emergence was 26 days, and the transition from emergence to the 4-6 leaf rosette stage took 32 days. From emergence to 50% flowering, 196 days elapsed, followed by 211 days to 50% capsule formation and 255 days to harvest.

Table 2. Sowing, Emergence, 4-6 Leaf Rosette Stage, 50% Flowering, 50% Capsule Formation, and Harvest of Turnip Rape Pure Lines

Growth stage	**Sowing**	**Emergence**	**4-6 leaf rosette stage**	**50% flowering**	**50% capsule formation**	**Harvest**
Date	15-Sep-2019	11-Oct-2019	12-Nov-2019	25-Apr-2020	10-May-2020	27-Jun-2020
Days from sowing	0	26	-	-	-	-
Days from emergence	-	-	32	196	211	255

The six pure lines of turnip rape exhibited considerable variation in several morphological and yield-related traits, as shown in Table 3. Although plant height and the number of lateral branches did not differ significantly among the lines ($p > 0.01$), the numerical differences indicate relatively narrow genetic variation for these traits. Plant height ranged from 141.40 cm (Bursa) to 156.35 cm (Tekirdağ3), suggesting that all lines possess a similar growth habit and biomass potential.

Table 3. Morphological Traits and Seed Yield of Six Pure Lines of Turnip Rape

Line	Plant height (cm)	Lateral branches per plant (branch/plant)	Capsules per plant (capsule/plant)	Seeds per capsule (seed/capsule)	Seed yield (kg/da)	Thousand seed weight (g)
Tekirdağ1 pureline	153.00	6.15	324.8 a	18.50 bc	365.71 ab	1.87
Bursa pureline	141.40	5.95	297.8 a	21.80 a	383.10 ab	1.87
Tekirdağ2 pureline	152.23	6.75	296.6 a	18.13 bc	405.79 ab	2.03
Türkiye pureline	145.60	6.45	233.65 b	19.55 ab	348.73 b	2.00
Tokat pureline	151.30	5.50	343.55 a	16.33 c	378.47 ab	2.02
Tekirdağ3 pureline	156.35	5.50	201.05 b	19.50 abc	407.99 a	2.02
Source of variation (%)	7,46	31,51	14,81	11,30	10,32	5,59
LSD (0.01) = 2.10 (24 df)	ns	ns	**	**	**	ns

Significance: ** = significant at $p < 0.01$; ns = not significant

The six pure lines of turnip rape exhibited considerable variation in several morphological and yield-related traits, as presented in Table 3. Although plant height (cm) and the number of lateral branches per plant (branch/plant) did not differ significantly among the lines ($p > 0.01$), the numerical differences suggest relatively narrow genetic variation for these traits. Plant height ranged from 141.40 cm (Bursa) to 156.35 cm (Tekirdağ3), indicating that all lines share a similar growth habit and biomass potential. The number of lateral branches varied from 5.50 to 6.75 branches per plant.

Significant differences were observed in the number of capsules per plant (capsule/plant), seeds per capsule (seed/capsule), and seed yield (kg/da) ($p < 0.01$). Tekirdağ1, Bursa, Tekir-dağ2, and Tokat formed a statistically similar group with higher capsule numbers, while Türkiye and Tekirdağ3 produced significantly fewer capsules. Despite producing fewer cap-sules, Tekirdağ3 achieved the highest seed yield (407.99 kg/da), likely due to its relatively high number of seeds per capsule (19.50 seed/capsule) and comparable thousand seed weight (2.02 g), suggesting a more efficient reproductive allocation that compensates for lower capsule production. The differences in seed yield among the pure lines likely reflect their adaptation and genetic potential under the existing agro-climatic conditions (Anjum et al., 2005; Kayaçetin, 2021).

Tokat produced the highest number of capsules per plant (343.55 capsule/plant), but its seed yield remained moderate (378.47 kg/da), which may be associated with its lower number of seeds per capsule (16.33 seed/capsule). Conversely, Bursa exhibited the highest seed number per capsule (21.80 seed/capsule), resulting in relatively high seed yield (383.10 kg/da) despite having fewer capsules than Tokat. These results emphasize that both capsule number and seed set are crucial determinants of final seed yield.

Thousand seed weight (g) did not differ significantly among lines, ranging narrowly from 1.87 to 2.03 g, indicating limited variation in seed size. This suggests that seed weight was not a major factor contributing to yield differences in this study. Johnson et al. (2002), Mondal et al. (2018), and Kayaçetin (2020) report that significant variation among genotypes/lines of the same species grown under identical environmental conditions highlights the fundamental role of genetic factors in determining the yield potential of plants.

CONCLUSION

The results of this study indicate that among the evaluated turnip rape (*Brassica rapa* ssp. *oleifera*) lines, Tekirdağ3 achieved the highest seed yield despite producing fewer capsules, suggesting a promising genetic potential for yield improvement. Tekirdağ1, Bursa, Tekirdağ2, and Tokat also demonstrated competitive performance and may serve as valuable genetic resources, particularly for traits such as capsule number and seed set. The limited variation observed in plant height, lateral branching, and thousand seed weight indicates that future breeding efforts should prioritize enhancing seed set and capsule productivity, which were the primary factors contributing to yield differences in this study. Overall, these findings provide valuable insights for selecting high-performing lines and support their further evaluation under diverse environmental conditions.

ACKNOWLEDGMENTS

The author gratefully acknowledges the financial support of TÜBİTAK (The Scientific and Technological Research Council of Türkiye) under project number 1505-5190038. Special thanks are extended to Dr. Oğuzhan Aydın and all project team members for their valuable contributions. The author also thanks the Field Crops Central Research Institute (Ankara) and DB Agricultural Energy (Izmir), Türkiye, for their support.

REFERENCES

Anjum, R., Yousaf, M., Jahangir, M., Hussain, M., Nawaz, N., & Ahmed, A. (2005). Adaptation and yield potential of different genotypes of rapeseed and mustard under agro-climatic conditions of Bahawalpur. *International Journal of Agriculture and Biology, 7*, 609–611.

Aslan, V. (2023). An overview of biodiesel produced from 2nd generation feedstock: Mustard seed types. *BioEnergy Research, 16*(3), 1380–1400.

Bocianowski, J., Nowosad, K., Liersch, A., & Popławska, W. (2019). Genotype-by-environment interaction for seed yield in rapeseed (*Brassica napus* L.) using AMMI model. *Euphytica, 208*, 187.

Cartea, E., Haro-Bailón, D., Padilla, G., Obregón-Cano, S., Del Río-Celestino, M., & Ordás, A. (2019). Seed oil quality of *Brassica napus* and *Brassica rapa* germplasm from Northwestern Spain. *Foods, 8*(8), 292.

Fayyaz, L., & Afzal, M. (2014). Genetic diversity in *Brassica* species and *Eruca sativa* for yield-associated parameters. *Genetika, 46*(2), 537–543.

Franzen, D. W., & Lukach, J. (2007). *Fertilizing canola and mustard (SF-1122).* North Dakota State University Extension.

Grant, C. A., Derksen, D. A., Blackshaw, R. E., Entz, T., & Janzen, H. H. (2007). Differential response of weed and crop species to potassium and sulphur fertilizers. *Canadian Journal of Plant Science, 87*(2), 293–296.

Johnston, A. M., Tanaka, D. L., Miller, P. R., Brandt, S. A., Nielsen, D. C., Lafond, G. P., & Riveland, N. R. (2002). Oilseed crops for semiarid cropping systems in the northern Great Plains. *Agronomy Journal, 94*, 231–240.

Kalaycı, M. (2005). *Örneklerle JMP kullanımı ve tarımsal araştırmalar için varyans analiz modelleri.* Anadolu TAEM Yayınları.

Kayaçetin, F. (2019). Morphological characterization and relationships among some wild and domestic Turkish mustard genotypes. *Turkish Journal of Botany, 43*(4), 499–515.

Kayaçetin, F. (2020). Performance of some important agronomic characteristics of *Brassica juncea* L. genotypes under fall sowing at two locations of Ankara, Türkiye. *KSU Journal of Agriculture and Nature, 23*(4), 966–974.
Kayaçetin, F. (2021). Effect of environment on seed and oil yield of Turkish *Brassica rapa* L. genotypes. *Fresenius Environmental Bulletin, 30*(1), 60–69.
Kayaçetin, F. (2023). Comparison of some species in genus *Brassica* cultivated on clay-loamy soils under semi-arid agroecosystem for suitability to biodiesel production. *Energy Sources, Part A, 45*(4), 11963–11980.
Kayaçetin, F., Aydin, O., Unal, S., & Khawar, K. M. (2023). Determination of the growth and yield traits of some mustard species under semi-arid Central Anatolian conditions. *Genetika, 55*(3), 829–840.
Kayaçetin, F., Efeoglu, B., & Sarioglu, G. (2018). Evaluation of fatty acid compositions of wild and domestic Turkish mustard genotypes. *International Journal of Secondary Metabolite, 5*(4), 270–278.
Kayaçetin, F., Khawar, H. M., Aydin, O., Kinay, A., & Sameeullah, M. (2022). *Gıda ve enerji endüstrisine uygun hardal çeşitlerinin geliştirilmesi* (TÜBİTAK-1505 Proje Sonuç Raporu).
Kayaçetin, F., & Aydin, O. (2024). Growth and yield of local and exotic white, brown, and black mustard lines sown in the spring season in Turkey. *Communications in Soil Science and Plant Analysis, 55*(22), 3447–3456.
Kinay, A., & Kayaçetin, F. (2023). Phenology, morphology, yield and quality characteristics of mustard species (*Brassica* spp.) suitable for energy sector. *Gesunde Pflanzen, 75*(5), 1953–1962.
Konuskan, D. B., Arslan, M., & Oksuz, A. (2019). Physicochemical properties of cold-pressed rapeseed, mustard and other oils. *Saudi Journal of Biological Sciences, 26*(2), 340–344.
Mondal, M. M. A., Malek, M. A., & Bhuiyan, M. S. H. (2018). The role of morpho-physiological attributes on the seed yield of *Brassica juncea*. *Acta Scientific Agriculture, 2*(5), 22–26.
Nisar, N. S., Mehmood, H., Nisar, S., Jamil, Z., Ahmad, N., Ghani, N., Oladipo, A. A., Waseem, R. Q., Latif, A. A., Ahmad, S. R., Iqbal, M., & Abbas, M. (2018). *Brassicaceae* family oil methyl esters blended with ULSD fuel: Comparison with fuel standards. *Renewable Energy, 117*, 393–403.
Nowosad, K., Liersch, A., Popławska, W., & Bocianowski, J. (2019). Genotype-by-environment interaction for seed yield in rapeseed (*Brassica napus* L.) using AMMI model. *Euphytica, 208*, 187.
Poddar, K. H., Sikand, G., Kalra, D., Wong, N., & Duell, P. B. (2021). Mustard oil and cardiovascular health: Why the controversy? *Journal of Clinical Lipidology, 16*(1), 13–22. https://doi.org/10.1016/j.jacl.2021.11.002
Rana, Q. U. A., Irfan, M., Ahmed, S., Hasan, F., Shah, A. A., Khan, S., Rehman, F. U., Khan, H., Ju, M., Li, W., et al. (2022). Biocatalytic transesterification of mustard oil for biodiesel production. *Biofuels, 13*(1), 69–76. https://doi.org/10.1080/17597269.2019.1655907
Shekhawat, K., Rathore, S. S., Premi, O. P., Kandpal, B. K., & Chauhan, J. S. (2012). Advances in agronomic management of Indian mustard. *International Journal of Agronomy, 2012*, 1–14.
Thomas, J., Kuruvilla, K. M., & Hrideek, T. K. (2012). Mustard. In *Handbook of Herbs and Spices* (pp. 388–398). Woodhead Publishing.

ACCUMULATOR PLANTS AND MICROPLASTICS

AKÜMÜLATÖR BİTKİLER VE MİKROPLASTİKLER

Bilal Can ERKAN
ORCID: 0009-0002-7011-5711
Tekirdağ Namık Kemal University, Faculty of Agriculture, Soil Science and Plant Nutrition
Tekirdağ-Türkiye

Uğur GÜNEŞ
ORCID: 0009-0006-9570-6541
Tekirdağ Namık Kemal University, Faculty of Agriculture, Soil Science and Plant Nutrition
Tekirdağ-Türkiye

Prof. Dr. Sevinç YEŞİLYURT
ORCID: 0000-0002-0062-0491
Tekirdağ Namık Kemal University, Faculty of Agriculture, Soil Science and Plant Nutrition
Tekirdağ-Türkiye

ÖZET

İnsanoğlunun çeşitli faaliyetleri sonucunda toprağa bulaşan atık plastikler, zaman içinde fiziksel ve biyolojik faktörlerin etkisi ile parçalanarak mikroplastiğe dönüşmektedir. Nüfusun artmasıyla paralel olarak atıkların da devasa boyutlara ulaşması nedeniyle bu durum günümüzün en önemli problemlerinden biri haline gelmiştir. Topraktaki mikroplastik kirliliği ortaya çıkmakta ve beraberinde çeşitli sorunları da meydana getirmektedir. Oluşan bu kirlilik sonucunda mikroplastikler, yapılan tarımsal faaliyetlerle birlikte insan vücuduna kadar taşınabilmekte ve çeşitli hastalıklara neden olmaktadır. Buradan da anlaşıldığı üzere mikroplastiklerin oluşturduğu kirlilik; sadece toprak için değil, insan sağlığı için de çok büyük riskler taşımaktadır. Problemin büyüklüğünü gözler önüne seren bu duruma çözüm odaklı yaklaşımın gerekliliği ortaya çıkmaktadır. Fitoremediasyon, toprak kirliliklerine ucuz ve etkili çözümler sunan ve bu konudaki değeri giderek daha fazla ortaya çıkan, bitkilerle çözüm sunan bir toprak iyileştirme yöntemidir. Buradan hareketle toprakta bulunan ağır metallerin temizliğinde kullanılmakta olan fitoremediasyonun, topraktaki mikroplastik varlığına da çözüm sunabileceği üzerine yoğunlaşarak, fitoremediasyonun temelini oluşturan akümülatör bitkiler derlenmiştir. Çevre dostu, ekonomik ve kolay uygulanabilir olan akümülatör bitkiler, topraktaki ağır metalleri kendi bünyelerinde biriktirerek toprak kirliliğini azaltmaktadırlar. Akümülatör bitkilerin ağır metalleri; topraktan alma sebepleri, alış mekanizmaları ve bünyelerinde biriktirme yöntemleri araştırıldığında bu bitkilerin topraktaki mikroplastik kirliliklerine de çözüm sunabilecekleri görülmüştür. Bu çalışmanın yeni çalışmalar için bir harita olması

hedeflenmekte ve akümülatör bitkiler kullanılarak yapılacak çalışmalarla birlikte mikroplastiğin toprakta, tarımda ve insan sağlığında ortaya çıkardığı sorunların minimum düzeye indirilmesi için yapılacak araştırmalara ışık tutması beklenmektedir.

Anahtar Kelimeler: Mikroplastikler, Akümülatör Bitkiler, Fitoremediasyon, Tarım, Toprak

ABSTRACT

Waste plastics, which contaminate the soil the soil resulting from various human activities, degrade into microplastics with the influence of physical and biological factors over time. Due to waste reaching colossal proportions in parallel with population growth, this situation has become a primary environmental challenge confronting contemporary society. Microplastic pollution in the soil is becoming prevalent, bringing with it a variety of associated problems. As a consequence of this pollution, microplastics can be transported into the human body through agricultural activities, causing various diseases. As is evident from this, the pollution caused by microplastics poses significant risks affecting the soil as well as human health. This situation, indicating the scale of the problem, highlights the necessity of a oriented toward practical solutions approach. Phytoremediation is a based on plants soil remediation method that offers cost effective and efficient solutions to soil pollution, with its value in this field becoming increasingly apparent. Based on this premise and focusing on the potential of phytoremediation currently used to clean heavy metals from soil to also provide a solution to microplastic pollution, the accumulator plants that form the basis of phytoremediation have been compiled. Environmentally friendly, economical, and easily applicable, accumulator plants reduce soil pollution by accumulating heavy metals from the soil within their own tissues. Upon investigating the reasons for heavy metal bioaccumulation, the uptake mechanisms, and the accumulation methods of accumulator plants, it has been demonstrated that these plants can also offer a solution to microplastic pollution in the soil.

Keywords: Microplastics, Accumulator plants, Phytoremediation, Agriculture, Soil

GİRİŞ

Toprak kirliliğine neden olan parametrelerden biri olan çok fazla miktarlarda üretilen plastik maddeler, her alanda yaygın olarak kullanılmakta ve çeşitli ürünlerde bulunmaktadır. Plastiklerin günlük hayatta oluşturduğu konfor, insanoğlunu plastik ürünlere muhtaç duruma düşürmüştür. İnsanoğlu plastiklerin kullanımından sonra atıkların toplanması ve doğru bir şekilde yönetiminin sağlanması halinde bu plastik maddelerin risk faktörü düşebileceği beklenmektedir. Fakat plastik atıklar günümüze kadar aşırı miktarlarda üretilmiş ve dikkatsizce çevreye dağılmış hale getirilmiştir. Plastik atıklar daha küçük parçacıklara ayrılarak uzun bir süreçte çevreye ve canlılara daha da zararlı bir hale gelmektedir. Mikro boyuta gelmiş bir plastik, çevresel ve insan kaynaklı sebeplerle kolay bir şekilde her yere dağılabilmekte ve su kaynaklarına karışabilmekte, sudaki canlılar tarafından yutularak bünyelerine alınabilmekte veya sulardaki zararlı organik maddeleri absorplayarak besin zincirine taşınmasına sebep olabilmektedir (Yurtsever, 2018; Çelik et al., 2022)

Mikroplastikler günümüzde insanların ve çevrenin sağlığına tehdit oluşturan önemli kirleticiler arasında bulunmaktadır. Dünya genelinde plastik üretimi, sanayi aktiviteleri, nüfus artışı, madencilik ve tarımda plastikültür uygulamalarının kullanımıyla önemli bir artış göstermiştir. Günümüzde doğaya atılan plastik miktarının önemli bir kısmını tarımsal araziler oluşturmaktadır. Karasal ekosistemlerdeki bu kirleticilerin toprak ve insan sağlığı için uzaklaştırılması gerekmektedir. Topraklarda biriken mikroplastiklerin giderilmesi için

fitoremediasyon teknolojileri ve akümülatör bitkilerin kullanımı, uygulanabilirlik, maliyet, zaman ve çevre dostluğu bakımından diğer yöntemlere göre ön plana çıkmaktadır. Fitoremediasyon, çevresel kirleticileri absorbe ederek bünyelerinde depolayabilen akümülatör bitkiler vasıtasıyla ortamın kirleticilerden arındırılmasında kullanılan yöntemlerin tümü olarak tanımlanmaktadır (De Souza Machado et al., 2019; Ding et al., 2022; Pal et al., 2025; Thapliyal et al., 2024; Wang et al., 2021)

Fitoremediasyon; uygulanabilir, bitki temelli çevreyi ıslah etme teknolojisine verilen isimdir. Fitoremediasyon yönteminde kullanılan akümülatör bitkiler ile organik ve inorganik kaynaklı kirleticilerle kirlenmiş alanları temizleme teknolojisi olarak ön plana çıkmaktadır. Fitoremediasyon tekniğinde en önemli avantajlar arasında; ekstra enerjiye gereksinim olmaması, yerinde arıtım sağlaması, uygulanabilirliği ve uygun maliyetli olması yer almaktadır. Ayrıca fitoremediasyon tekniği doğal kaynaklara zarar vermemektedir. Bu teknik, çevre bilincine sahip olan çoğu kişi tarafından da desteklenmektedir (Asante-Badu et al., 2020; Kafle et al., 2022; Yadav et al., 2022; Priya et al., 2023)

Bu çalışmada, ağır metalleri bünyelerinde biriktirme kapasitesine sahip akümülatör bitkilerin, mikroplastiklerle kirlenmiş toprakların iyileştirilmesindeki potansiyeli ele alınmış; bununla birlikte fitoremediasyonun çeşitli alt teknolojileri (fitostabilizasyon, fitoekstraksiyon, rizodegradasyon vb.) mikroplastik kirliliğinin azaltılmasındaki işlevleri değerlendirilmiştir. Bu alanda yapılacak çalışmalar, toprakta bulunan mikroplastiklerin giderilmesi, toprak sürdürülebilirliğinin sağlanması, ekolojik bütünlüğün korunması ve toprak yönetimi açısından önemli bir basamak olma potansiyelini taşımaktadır.

MİKROPLASTİKLER VE TARIM

Mikroplastiklerin Tanımı, Sınıflandırılması ve Çevresel Riskler

Plastik atıkların bir kısmı geri dönüştürülebilmekte, bir kısmı ise enerji geri dönüşümü için kullanılmaktadır. Geri kalan kısmı ise çöp alanlarına atılmaktadır. Bu eğilimin bu yönde devam etmesi halinde 2050 yılına kadar 12.000 Mt plastiğin çöplüklerde ve doğal ortamlarda bulunulacağı tahmin edilmektedir (Malankowska et al., 2021).

Boyutları 5 mm'den küçük olan plastik taneciklere mikroplastik denilmektedir. Literatürde mikroplastiğin tanımı olarak farklı ifadeler bulunmaktadır. Yaygın olarak kabul edilen görüş ise mikroplastiklerin 5 mm'den küçük tanecikler olduğu yönündedir. Yapılan çalışmalardan birinde yapılan bir diğer tanım ise elekten geçip geçememe durumu olarak belirtilmiştir. Başka bir tanımda ise mikroplastikler *Birincil ve ikincil kaynaklardan gelen 1 µm - 5000 µm boyutları arasında yer alan ve suda çözünmeyen polimer parçacıklar* olduğunu ifade etmiştir (Yurtsever, 2019; Soysal, 2024). Mikroplastikler oluşum biçimlerine göre birincil ve ikincil olmak üzere iki temel sınıfa ayrılmaktadır. Birincil mikroplastikler, üretim süreçleri sırasında doğrudan mikro boyutta üretilen parçacıklardır; kozmetik ürünlerde kullanılan aşındırıcı tanecikler, ilaç taşıyıcı sistemler ve çeşitli mühendislik uygulamalarında tercih edilen mikro boyutlu polimerler bu gruba örnek gösterilebilir. Endüstriyel kaynaklı bu mikroplastiklerin arıtma sistemleriyle uzaklaştırılması çoğu zaman güçtür. İkincil mikroplastikler ise daha büyük plastik materyallerin rüzgâr, güneş ışığı, sıcaklık değişimleri ve mekanik aşınma gibi çevresel etmenler altında zamanla parçalanması sonucu ortaya çıkmaktadır. (Can, 2022; Ding et al., 2022).

Mikroplastik Kaynakları

Tarımsal uygulamalardan kaynaklanan mikroplastik kirliliğinin en önemli kaynaklarından biri malçlama uygulamalarıdır. Tarımsal alanlarda yabancı ot kontrolü, toprak neminin korunması, sıcaklık düzenlenmesi ve verim artışı gibi amaçlarla yaygın biçimde kullanılan malç örtülerinin

büyük çoğunluğu düşük yoğunluklu polietilen temellidir. Bu plastik örtüler, tarla koşullarında uzun süre güneş ışığına maruz kalma, sıcaklık dalgalanmaları, yağış, rüzgâr ve toprağın fiziksel etkileri gibi çevresel stres faktörlerine dayanarak zamanla fotooksidasyon, termal bozunma ve mekanik aşınma süreçlerine uğrar. Bu süreçler polietilen yapının giderek zayıflamasına ve örtünün önce küçük parçacıklara, daha sonra da mikroplastik boyutuna ayrışmasına yol açmaktadır. Malçların genellikle hasat sonrası topraktan tam olarak kaldırılamaması, parçalanmış plastik kalıntılarının toprakta birikmesine ve uzun vadede toprak ekosistemlerine, mikroorganizmalara, bitki büyümesine ve nihayetinde gıda zincirine geçebilecek mikroplastik yükünün artmasına neden olmaktadır. Bu durum, tarımsal üretimde plastik kullanımının sürdürülebilirliği ve toprak sağlığı açısından önemli çevresel riskler doğurmaktadır. (Garua & Sharma, 2021; Arı ve Öğüt, 2021).

Tarım topraklarına mikroplastik taşınımında birçok faktör önemli bir kaynak oluştursa da malçlama dışında pek çok makroplastik zamanla mikroplastiklere dönüşerek toprağın kirlenmesine katkıda bulunmaktadır. Tarımsal üretimde yoğun olarak kullanılan plastik sulama boruları, seracılıkta kullanılan örtüler, fide tepsileri, bitki destek materyalleri ve ambalaj malzemeleri zaman içinde güneş ışığı, sıcaklık değişimleri, rüzgâr etkisi ve mekanik aşınma gibi çevresel faktörlerle parçalanarak küçük plastik parçalara ayrılmaktadır. Bunun yanı sıra, tarım alanlarına yakın bölgelerdeki plastik ambalaj atıkları, paketleme malzemeleri, plastik ipler, ağlar ve tarım makinelerinde kullanılan plastik aksamların aşınması da toprağa plastik parçacık taşınmasına yol açmaktadır. (Zhang et al., 2022).

Mikroplastiklerin Bitki Üzerindeki Etkileri

Toprağa karışan farklı türdeki mikroplastiklerin (membranöz polietilen, lifli polipropilen, mikroküre polipropilen) toprak enzim aktiviteleri ve mikrobiyal topluluklar üzerindeki etkileri değerlendirildiğinde 14. günde Lifli polipropilen, bakteri miktarını kontrol gurubuna göre düşürmüştür. Plastik yüzeylerinin topraktan farklı, kendine özgü bir habitat oluşturduğunu da ortaya koymuştur. Plastik yüzeylerde bulunan mikrobiyal topluluklar topraktaki mikrobiyal topluluklara göre belirgin şekilde farklılaşmıştır. Özellikle Actinobacteria ait cinsler (*Aeromicrobium, Streptomyces, Mycobacterium, Janibacter, Nocardia, Arthrobacter*) plastik yüzeylerine yerleşme eğilimi göstermiştir. Bu durum, plastiklerin zararlı mikroorganizmaları taşıyabilecek bir vektör görevi görebileceğini düşündürmektedir (Yi et al., 2021).

Mikroplastiklerin bitkiler üzerinde olumsuz etkileri incelendiğinde bitki büyümesini etkileyerek genel biyokütleyi azaltabilir, kök ve sürgün gelişimini engelleyebilir, yaprak gelişimini olumsuz etkileyebilir, çimlenmeyi inhibe edebilir, oksidatif strese neden olabilir, fotosentez ve klorofil üzerinde negatif etki gösterebilir, metabolik ve genetik bozulmalara sebebiyet verebilir, besin ve su alımı dengelerini bozabilir, toprağa olan etkilerinden dolayı dolaylı olarak mikrobiyal ve enzimatik aktiviteyi bozabilir, toksik maddelere vektörlük edebilir, zararlı katkı maddeleri ve biyobozunur mikroplastikler için zararlı yan ürünler toprağa salınabilir. Ayrıca mikroplastikler besin zincirine karışarak insan sağlığını riske atabilir (Akça et al., 2024; Colzi et al., 2022; Li et al., 2022; Wang et al., 2021; Yi ve ark., 2021; Yu et al., 2025).

Fitoremediasyon

Fitoremediasyon, bitkilerin kullanılması yoluyla toprak veya su vb. ortamlarında bulunan kirleticilerin uzaklaştırılması, dönüştürülmesi, azaltılması ya da etkisiz hâle getirilmesini hedefleyen bütüncül teknikler bütünü olarak tanımlanmaktadır. Bu yöntem, alternatif fiziksel ve kimyasal arıtım yöntemleriyle karşılaştırıldığında oldukça düşük maliyetlidir; geleneksel kirlilik giderim tekniklerinin maliyetinin yalnızca küçük bir bölümüne karşılık gelmekte ve yoğun iş gücü gereksinimi duymamaktadır. Bunun yanında, uygulama sahasında estetik bir görünüm oluşturması ve kamuoyu tarafından daha kolay kabul görmesi önemli avantajlar

arasındadır. Fitoremediasyonun yerinde uygulanması, kirleticilerin başka ortamlara taşınmasını engelleyerek ikincil kirlilik riskini azaltmakta; ayrıca yalnızca tek bir kirleticiyle sınırlı kalmayıp çoklu kirleticilerin eş zamanlı giderimine imkân tanımaktadır. Bu özellikleri fitoremediasyonu, çevresel kirleticilerin sürdürülebilir yönetiminde etkili ve tercih edilen bir yöntem hâline getirmektedir (Adiloğlu, 2018; Adiloğlu ve Gürgan, 2020). Fitoremediasyon teknolojisi 9 başlık altında; fitoekstraksiyon, rizofiltrasyon, fitostabilizasyon, rizodegredasyon, fitodegredasyon, fitovolatilizasyon, hidrolik kontrol, vejatatif örtü sistemleri ve kıyı tampon şeritleri olarak sıralanabilir (Hamutoğlu et al., 2012; Sertkahya, 2025).

Fitoremediasyon Teknolojileri

Fitoekstraksiyon (fitoakümülasyon, fitoabsorpsiyon veya fitosekestrasyon olarak da bilinir); kirleticilerin bitki kökleri tarafından kirletici ortamdan alınarak bitkinin toprak üstü biyokütlesine ya da başka bir deyişle sürgünlere taşınması, burada biriktirilmesi ve ardından hasat edilerek uzaklaştırılması işlemidir. Bu yöntem toprak, sediment ve çamurda uygulanan, kirleticilerden metaller, metalloidler ve radyonükleidlerin giderimini sağlamak amacıyla kullanılan, kirleticiyi alma ve uzaklaştırma amaçlı tekniktir. Bu teknikte kullanılan bitkilere; hindistan hardalı, *pennycress alyssum*, ayçiçeği ve hibrit kavaklar örnek olarak gösterilebilir (Hamutoğlu et al., 2012; Wang et al., 2021; Sertkahya, 2025).

Rizofiltrasyon, sucul ve karasal ortamdaki kirletici maddelerin bitki köklere tarafından absorplanarak çöktürülmesidir. Kirleticiler ya bitki kökleri tarafından emilmekte ya da kökün yüzeyinde absorbe edilmektedir. Bu teknik, özellikle yeraltı sularının kirleticilerden arındırılmasında etkilidir. Rizofiltrasyon; yüzey ve yer altı suyunda uygulanan, kirleticilerden metaller ve radyonükleidlerin giderimini sağlamak amacıyla kullanılan, kirleticiyi alma ve uzaklaştırma amaçlı yöntemlerdendir. Bu teknikte kullanılan bitkilere; ayçiçeği, hindistan hardalı ve su sümbülü örnek olarak gösterilebilir (Doğan, 2017; Hamutoğlu et al., 2012; Sertkahya, 2025).

Fitostabilizasyon, topraktaki kirleticilerin bitki kökleri tarafından absorbe edilerek immobilize edilmesi ya da başka bir deyişle köklere sabitlenmesidir. Bu yöntemle kirletici maddelerin taşınımı engellenmektedir. Hg, Cd, Pb, Cu gibi metallerce kirlemiş toprakların onarımı bu yöntemle yapılabilmektedir. Toprak, sediment ve çamurda ortamına kontamine, kirleticilerden As, Cd, Cr, Cu, Hs, Pb ve Zn giderimini sağlamak amacıyla kullanılan Fitostabilizasyon, kirleticiyi etkisizleştirme amaçlı kullanılmaktadır. Bu teknikte kullanılan bitkilere; hindistan hardalı, hibrit kavaklar ve çimler örnek olarak gösterilebilir (Aybar et al., 2015; Adiloğlu, 2018; Sertkahya, 2025).

Rizodegredasyon, bitki kökleri ve bu köklerde bulunan çeşitli mikroorganizmaların metabolik faaliyetleri sonucunda ortamdaki organik kirleticilerin bozunuma uğratarak giderimidir. Petrollü ve aromatik hidrokarbonlar, klorlu çözücüler, pentaklorofenol, poliklorinatlı bifeniller, benzen, etilbenzen, tolüen, ksilen ve pestisitler gibi organik kökenli kirletici bu yöntem ile etkisiz hale getirilmektedir. Toprak ve yer altı suyunda uygulanan, kirleticilerden organik bileşiklerin giderimini sağlamak amacıyla kullanılan, kirletici gidermeyi hedeflemektedir. Bu teknikte kullanılan bitkilere; kırmızı dut ve çimler örnek olarak gösterilebilir (Doğan, 2017; Tiryaki & Potur, 2017; Adiloğlu, 2018)

Fitodegredasyon, ya da diğer bir adıyla fitotransformasyon kirleticilerin bitki bünyesinde metabolik aktiviteler sonucunda daha az zararlı bir forma dönüştürülme işlemidir. Bu yöntemle toprak, sediment, çamur ya da yer altı sularındaki pestisitler, klorlu birleşikler ya da fenol birleşiklerin giderilebilmektedir. Kirleticilerin kontamine olduğu ortamlar, toprak, sediment, çamur, yer altı suyu ve yüzey suyunda uygulanan, kirleticilerden organik bileşikler, klorinat çözücüler, herbisitler ve fenollerin giderimini sağlamak amacıyla kullanılan, kirletici giderme

amaçlı tekniktir. Bu teknikte alg, hibrit kavaklar, siyah söğüt ve servi kullanılabilmektedir (Hamutoğlu et al., 2012; Tiryaki & Potur, 2017; Sertkahya, 2025).

Fitovolatilizasyon, organik ve inorganik kirleticilerin ortamdan alınarak bitki bünyesinde daha az toksik bir forma dönüştürülmesi ya da aynı formda atmosfere salınımıdır. Fitovolatilizasyon; toprak, sediment, çamur ve yer altı suyunda uygulanan, kirleticilerden klorinat çözücüler ve bazı inorganiklerin (Se, Hg, As) giderimini sağlamak amacıyla kullanılan, kirleticiyi buharlaştırma amaçlı uygulanmaktadır. Bu teknikte kullanılan bitkilere; kavaklar, yonca ve hindistan hardalı örnek olarak gösterilebilir. (Sangeeta Mukhopadhyay & Maiti, 2010; Adiloğlu, 2018).

Hidrolik kontrol, bitkiler vasıtasıyla yer altı sularındaki kirleticilerin birikimi ve taşmasını önlemek ve veya istenen düzeyde tutmak için uygulanan yöntemi ifade etmektedir. Hidrolik kontrol yönteminde yeşil ıslak yöntemlerinin birden fazlası aynı anda kullanılır. Avantajı ıslah etki alanının çok geniş olmasıdır. Mevsim ve iklim şartlarına göre su alınımının değişmesi ise bu yöntemin dezavantajı olarak öne çıkmaktadır. Yüzey suyu ve yer altı suyunda uygulanan, kirleticilerden suda çözünen organik ve inorganiklerin giderimini sağlamak amacıyla kullanılan, kirletici bozunumu amaçlamaktadır. Bu teknikte kullanılan bitkilere; hibrit kavaklar ve söğüt örnek olarak gösterilebilir (Vanlı, 2007; Hamutoğlu et al., 2012; Adiloğlu, 2018; Sertkahya, 2025)

Vejetatif örtü sistemleri, toprak içindeki kirleticilerin yüzeydeki bitki sistemi ile kontrol edilmesi işlemidir. Bu yöntem topraktaki su kaybını azaltmayı ve su tutumunu maksimize etmeyi amaçlar ve yeşil ıslah amacıyla kullanılmaktadır. Sistem bitkiyi bir örtü olarak kullanarak su infiltrasyonunu azaltır ve alt tabakalarda bulunan kirliliği oluşturan maddelerin bozunuma uğratmaktadır. Suyun dikey akışının toprak altındaki kirleticiye ulaşımının bitki tarafından engellenmesini sağlayan vejetatif örtü sistemleri; toprak, sediment ve çamurda uygulanan, kirleticilerden organik ve inorganik bileşiklerin giderimini sağlamak amacıyla kullanılan, erozyon kontrolü içinde kullanılmaktadır. Bu teknikte kullanılan bitkilere; kavaklar ve çimler örnek olarak gösterilebilir (Adiloğlu, 2018; Yeşilyurt & Gurgan, 2023)

Kıyı tampon şeritleri, akarsulara doğru akmakta olan yer altı suları ve yüzey sularındaki kirletici faktörlerin giderimini sağlamak için kıyı boyunca şeriler şeklinde bitkilerin ekimidir. Bu yöntemde amaç kirliliğin çevreye ve taban sularına bulaşını önlemektir. Yapılan bazı çalışmalara göre buffer strips yöntemi toprak erozyonunu %90 seviyesinde azaltmış ve herbisit akışını %42-70 oranlarında önlemiştir. Ek olarak suda bulunan sediment, fosfor, azot, fekal koliformlar ve pestisitlerde de azalma meydana gelmiştir. Kirleticilerin su ile dere vb. akarsulara taşınmasının engellenmesini sağlayan kıyı tampon şeritleri; yüzey ve yer altı suyunda uygulanan, kirleticilerden suda çözünen organik ve inorganiklerin giderimini sağlamak amacıyla kullanılan, kirletici gidermeyi amaçlamaktadır. Bu teknikte kavaklar kullanılabilmektedir (Vanlı, 2007; Hamutoğlu et al., 2012; Adiloğlu, 2018; Yeşilyurt, 2023).

Akümülatör Bitkiler

Akümülatör bitkiler, yüksek kirletici konsantrasyonunun olduğu alanlarda yetişebilen ve bu kirleticileri kökleri aracılığıyla kök ya da diğer doku ve organlarında depolayabilen bitkilere akümülatör ya da hiperakümülatör bitkiler denir (Güneş & Bozkurt, 2021).

Fitoremediasyon teknolojilerinde akümülatör bitki olarak Poaceae, Brassicaceae, Fabaceae, Salicaceae, Asteraceae, Chenopodiaceae, Cyperaceae, Careophylaceae, Cannabaceae, Amaranthaceae, Cannaceae, Pontederiaceae ve Typhaceae; familyaları en çok kullanılan familyalardır. Her bir familya grubu kendi içinde avantaj ve dezavantajlara sahiptir. Kontamine olan alanlarda giderim yapılacak alana göre uygun familya seçimi yapılarak fitoremediasyon yöntemleri uygulanır. (Gawronski & Gawronska, 2007).

Fitoremediasyon çalışmalarında hem otsu hem de odunsu pek çok bitki türü ağır metal, organik kirletici ve besin fazlalığı gibi çevresel sorunların giderilmesinde etkin rol oynamaktadır. Derin ve yoğun kök yapısına sahip Vetiver grass (*Vetiveria zizanioides*), ağır metal toleransı yüksek olması nedeniyle geniş çaplı toprak iyileştirme uygulamalarında öne çıkarken; Bermuda grass (*Cynodon dactylon*), Bahia grass (Paspalum notatum) ve Switch grass (*Panicum virgatum*) gibi çim türleri hem metal stabilizasyonunda hem de hidrokarbon bozunumunda kullanılan dayanıklı türlerdir. Ağır metal fitoekstraksiyonunda klasik model bitkilerden olan Sunflower (*Helianthus annuus*) ve Indian mustard (*Brassica juncea*) özellikle Pb, Cd ve Zn gibi toksik elementleri bünyelerine alma kapasiteleriyle dikkat çekmektedir. Benzer şekilde Periwinkle (*Catharanthus roseus*), Nightshade (*Solanum nigrum*) ve Lambsquarters (*Chenopodium berlandieri*) gibi türlerin hiperakümülatör özellikleri, kirlenmiş alanların hedef metal seçiciliği gerektiren iyileştirme çalışmalarında önem taşımaktadır. Sulak alan ve atıksu arıtımında yaygın kullanılan *Typha angustifolia, Eichhornia crassipes, Lemna minor* ve *Phragmites australis* gibi hidrofiller hem ağır metalleri hem de organik kirleticileri yüksek verimle uzaklaştırma yetenekleri sayesinde doğal arıtma sistemlerinin temel bileşenleri hâline gelmiştir. Odunsu türlerden Poplar (*Populus* spp.), hızlı büyümesi ve kök bölgesinde organik kirleticilerin biyodegradasyonunu hızlandırması nedeniyle özellikle klorlu solvent ve petrol türevlerinin bulunduğu alanlarda kullanılmaktadır. Ayrıca *Kochia scoparia, Hordeum jubatum, Andropogon gerardii, Sorghastrum nutans, Elymus canadensis, Agropyron cristatum, Festuca arundinacea, Thinopyrum elongatum* ve *Chloris gayana* gibi kuraklığa ve tuzluluğa dayanıklı türler, ağır metalce zengin bozulmuş topraklarda bitkisel örtünün yeniden tesis edilmesine katkı sağlamaktadır. Besin fazlasının uzaklaştırılması ve toprak kalitesinin yükseltilmesi açısından *Medicago sativa, Lathyrus sylvestris* gibi baklagiller ile *Daucus carota* gibi bazı tarımsal türler de hem fitostabilizasyon hem de toprak-biyota etkileşimlerini düzenlemede önemli bir ekolojik işlev üstlenmektedir. Bu geniş tür çeşitliliği, fitoremediasyonun farklı kirletici türlerine ve farklı ekosistem koşullarına uyarlanabilir, maliyeti düşük ve çevre dostu bir biyoteknoloji olduğunu açıkça göstermektedir (Sinha et al., 2007; Adiloğlu and Pamay, 2021; Yeşilyurt, 2023).

Mikroplastiklerin, bitki kökleri tarafından emilerek toprak üstü aksamlara taşınabileceğini de belirterek, topraklardan mikroplastik gideriminin kök immobilizasyonu ya da ekstraksiyonu yoluyla mümkün olduğunu savunmuşlardır. Kök immobilizasyonunun mikroplastikleri ortamdan uzaklaştırmadığını ancak hareketliliklerini sınırlayarak biyoyararlanımlarını azalttığını ve ekolojik riskleri düşürdüğü ifade edilmiştir. Su ortamlarında bulunan *Thalassia testudinum, Lemna minor, Fucus vesiculosus* gibi su bitkilerinin mikroplastikleri absorbe ederek hareketliklerini sınırlandığını çalışmalarında belirtmişlerdir. Mikroplastik gideriminde ekstraksiyonun (fitoekstraksiyon), immobilizasyonun aksine mikroplastikleri ortamdan uzaklaştırdığını ifade edilmiştir. Yabani otlar ve su mercimeği (*Lemna minor*) gibi vasküler bitkilerin mikroplastikleri biriktirilebildiği ve plastik ayrıştırıcı mikroorganizmaların mikroplastik yüzeylerinde kolonize olarak mikroplastiklerin karbon omurgalarını depolimerize ettiğini, mikrobiyal olarak güçlendirilmiş fitoremediasyon yöntemi ile mikroplastik gideriminde kullanılabileceğini belirtmişlerdir (Li et al., 2024)

SONUÇ

Mikroplastiklerin tarım topraklarına karışması, yalnızca toprak yapısını ve ekolojik fonksiyonları bozmakla kalmayıp, bitkilerin kök bölgesine, tarımsal ürünlere ve çeşitli canlılara geçişiyle birlikte besin zinciri boyunca ilerleyen ciddi bir çevresel ve sağlık sorununa dönüşmektedir. Mikroplastiklerin insan vücuduna kadar taşınabilmesi ve çeşitli fizyolojik ile metabolik sorunlara yol açabilmesi, bu kirliliğin göz ardı edilemeyecek kadar önemli olduğunu açıkça göstermektedir. Ancak literatür incelendiğinde, mikroplastiklerin topraktan giderimine yönelik çalışmaların sınırlı olduğu ve özellikle bitki temelli arıtım yaklaşımlarının yeterince

araştırılmadığı görülmektedir. Oysa fitoremediasyonun bilinen mekanizmaları ve akümülatör bitkilerin kirletici biriktirme kapasitesi dikkate alındığında, bu bitkilerin topraktaki mikroplastiklerin azaltılmasında potansiyel bir çözüm sunabileceği anlaşılmaktadır. Bu çalışma, akümülatör bitkilerin mikroplastik kirliliğinin gideriminde kullanılabileceğine ilişkin bilimsel bir farkındalık oluşturmuş ve bu alandaki bilgi eksikliğine dikkat çekmiştir. Gelecekte yapılacak kapsamlı deneysel çalışmaların, mikroplastik-fitoremediasyon ilişkisini daha iyi aydınlatması, yöntemlerin geliştirilmesi ve sürdürülebilir tarım uygulamalarına katkı sağlaması beklenmektedir. Böylece toprak ekosistemlerinin korunması ve insan sağlığının güvence altına alınması adına önemli ilerlemeler kaydedilebilecektir.

Kaynaklar

Adiloğlu, S. (2018). Book title: Advances in Bioremediation and Phytoremediation Chapter title "Heavy Metal Removal with Phytoremediation". ISBN 978-953-51-3957-7. Edited by Naofumi Shiomi, ISBN 978-953-51-3958-4,

Adiloğlu, S., & Gürgan M. (2020). Karoline Møller (Editor) Book title: Brassica napus: Cultivation and Uses. Chapter title: Brassica napus: Phytoremediation. Nova Science Publishers. p, 134. ISBN:978-1-53618-191-3.

Adiloğlu, S., & Pamay S. (2021). James C. Flores (Editor) Book title: The Future of Phytoremediation. Chapter title: Phytoremediation and Hyperacumulative Families. Nova Science Publishers, Inc. ISBN:978-1-53619-625-2

Akça, M. O., Sözüdoğru Ok, S., Akça, H., Taşkın, M. B., & Deniz, K. (2024). The influence of microplastics on physiological characteristics of lettuce plant (Lactuca Sativa l.) and soil properties. Toprak Bilimi ve Bitki Besleme Dergisi, 12(2), 159–171. https://doi.org/10.33409/tbbbd.1526281

Arı, M., & Öğüt, S. (2021). Mikroplastikler ve çevresel etkileri. Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 9(2), 864-877.

Asante-Badu, B., Kgorutla, L. E., Li, S. S., Danso, P. O., Xue, Z., & Qiang, G. (2020). Phytoremediation of organic and inorganic compounds in a natural and an agricultural environment: A review. Applied Ecology and Environmental Research, 18, 6875–6904. https://doi.org/10.15666/aeer/1805_68756904

Ashraf, S., Ali, Q., Zahir, Z. A., Ashraf, S., & Asghar, H. N. (2019). Phytoremediation: Environmentally sustainable way for reclamation of heavy metal polluted soils. Ecotoxicology and Environmental Safety, 174, 714–727.

Aybar, M., Bilgin, A., & Sağlam, B. (2015). Fitoremediasyon yöntemi ile topraktaki ağır metallerin giderimi. Doğal Afetler ve Çevre Dergisi, 1(1-2), 59–65.

Can, T. (2022). Atıksu arıtma tesislerinde mikroplastik gideriminin araştırılması (Master's thesis, Bursa Uludag Üniversitesi, Fen Bilimleri Enstitüsü Çevre Mühendisliği Anabilim Dalı (Turkey).

Colzi, I., Renna, L., Bianchi, E., Castellani, M. B., Coppi, A., Pignattelli, S., Loppi, S., & Gonnelli, C. (2022). Impact of microplastics on growth, photosynthesis and essential elements in Cucurbita pepo L. J. Hazard Mater, 423(Pt B), 127238. https://doi.org/10.1016/j.jhazmat.2021.127238

Çelik, E., Yüksel, D., & Turgay, Ö. (2022). Farklı Ekosistemlerde Mikroplastik Kirlilik: Oluşum, Toksisite ve Riskler. Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 5(3), 1815-1842.

De Souza Machado, A. A., Lau, C. W., Kloas, W., Bergmann, J., Bachelier, J. B., Faltin, E., Becker, R., Görlich, A. S., & Rillig, M. C. (2019). Microplastics Can Change Soil Properties and Affect Plant Performance. Environmental Science & Technology, 53(10), 6044–6052. https://doi.org/10.1021/acs.est.9b01339

Ding, L., Huang, D., Ouyang, Z., & Guo, X. (2022). The effects of microplastics on soil ecosystem: A review. Current Opinion in Environmental Science & Health, 26, 100344. https://doi.org/https://doi.org/10.1016/j.coesh.2022.100344

Doğan, M. (2017). In vitro koşullarda çoğaltılan bazı su bitkilerinin fitoremediasyon potansiyellerinin araştırılması Karamanoğlu Mehmetbey Üniversitesi. Fen Bilimleri Enstitüsü, Biyoloji Anabilim Dalı, Karaman.

Garua, B., & Sharma, J. G. (2021). Accumulation of plastics in terrestrial crop plants and its impact on the plant growth. Journal of Applied Biology & Biotechnology. https://doi.org/10.7324/jabb.2021.9603

Gawronski, S. W., & Gawronska, H. (2007). Plant Taxonomy For Phytoremediation. Advanced Science and Technology for Biological Decontamination of Sites Affected by Chemical and Radiological Nuclear Agents, (pp. 79-88). Dordrecht: Springer Netherlands.

Güneş, F., & Bozkurt, S. (2021). Bazı Hiperakümülatör Bitkiler ve Özellikleri. Türk Bilimsel Derlemeler Dergisi, 14(1), 67–90.

Hamutoğlu, R., Dinçsoy, A. B., Cansaran-duman, D., & Aras, S. (2012). Biosorption, adsorption, phytoremediation methods and applications. Türk Hijyen ve Deneysel Biyoloji Dergisi, 69(4), 235–253.

Kafle, A., Timilsina, A., Gautam, A., Adhikari, K., Bhattarai, A., & Aryal, N. (2022). Phytoremediation: Mechanisms, plant selection and enhancement by natural and synthetic agents. Environmental Advances, 8, 100203.

Li, X., Wang, X., Ren, C., Palansooriya, K. N., Wang, Z., & Chang, S. X. (2024). Microplastic pollution: Phytotoxicity, environmental risks, and phytoremediation strategies. Critical Reviews in Environmental Science and Technology, 54(6), 486–507. https://doi.org/10.1080/10643389.2023.2252310

Malankowska, M., Echaide-Gorriz, C., & Coronas, J. (2021). Microplastics in marine environment: a review on sources, classification, and potential remediation by membrane technology. Environmental Science: Water Research & Technology, 7(2), 243–258. https://doi.org/10.1039/d0ew00802h

Pal, S., Dutta Gupta, S., Guha, P. S., & Saha, N. (2025). Microplastics as emerging stressors in plants: biochemical and metabolic responses. Environmental Geochemistry and Health, 47(12), 530. https://doi.org/10.1007/s10653-025-02839-5

Prata, J. C., da Costa, J. P., Lopes, I., Duarte, A. C., & Rocha-Santos, T. (2020). Environmental exposure to microplastics: An overview on possible human health effects. Science of The Total Environment, 702, 134455.

Priya, A. K., Muruganandam, M., Ali, S. S., & Kornaros, M. (2023). Clean-Up of Heavy Metals from Contaminated Soil by Phytoremediation: A Multidisciplinary and Eco-Friendly Approach. Toxics, 11(5), 422.

Sangeeta Mukhopadhyay, S. M., & Maiti, S. K. (2010). Phytoremediation of metal enriched mine waste: a review. American-Eurasian Journal of Agricultural & Environmental Sciences, 9(5), 560–575.

Sertkahya, M., & Yeşilyurt, S. (2025). Türkiye'de Bitkisel ve Tarımsal Üretim Alanında Yapılan Araştırmaların Bibliyometrik Analizi. International Journal of Advanced Natural Sciences and Engineering Researches. 9(2), 111-140.

Sinha, R. K., Herat, S., & Tandon, P. K. (2007). Phytoremediation: Role of Plants in Contaminated Site Management. In S. N. Singh & R. D. Tripathi (Eds.), Environmental Bioremediation Technologies (pp. 315–330). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-34793-4_14

Soysal, M. (2024). Mikroplastik Tespitinde Güncel Stratejiler: Türkiye Örneği. JENAS Journal of Environmental and Natural Studies, 6(2), 107-116.

Thapliyal, C., Priya, A., Singh, S. B., Bahuguna, V., & Daverey, A. (2024). Potential strategies for bioremediation of microplastic contaminated soil. Environmental Chemistry and Ecotoxicology, 6, 117–131.

Tiryaki, O., & Potur, T. (2017). An Important Tool for Purifying Pesticides from Soil: Phytoremediation. Erciyes Üniversitesi Fen Bilimleri Enstitüsü Fen Bilimleri Dergisi, 33(1), 59–68.

Vanlı, Ö. (2007). Pb, Cd, B Elementlerinin Topraklardan Şelat Destekli Fitoremediasyon Yöntemiyle Giderilmesi. Master Thesis, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü.Türkiye

Wang, F., Wang, X., & Song, N. (2021). Polyethylene microplastics increase cadmium uptake in lettuce (Lactuca sativa L.) by altering the soil microenvironment. Science of The Total Environment, 784, 147133.

Yadav, R., Singh, S., Kumar, A., & Singh, A. N. (2022). Phytoremediation: A wonderful cost-effective tool. In S. Kathi, S. Devipriya, & K. Thamaraiselvi (Eds.), Cost Effective Technologies for Solid Waste and Wastewater Treatment (pp. 179–208). Elsevier.

Yeşilyurt, S., (2023). Phytoremediation method and Brassica family: Removal of chromium, cadmium and lead accumulation with broccoli (Brassica oleracea var. italica) Results in Chemistry, Aralık 2023, 6 (101005)

Yeşilyurt, S., & Gurgan, M., (2023). Phytoremediation Technologies: From Lab Scale to Forest Scale Journey. Iksad Publications–Haziran 2023. Turkey. ISBN: 978-625-367-101-3. pp.465

Yi, M., Zhou, S., Zhang, L., & Ding, S. (2021). The effects of three different microplastics on enzyme activities and microbial communities in soil. Water Environ Res, 93(1), 24–32. https://doi.org/10.1002/wer.1327

Yu, Y., Zhang, Z., Xue, J., Liu, L., & Yao, H. (2025). Polyethylene microplastic impairs soil gross nitrification and reduces fertilizer-derived nitrogen uptake in rice. Journal of Hazardous Materials, 499, 140145.

Yurtsever, M. (2018). Küresel plastik kirliliği nano-mikroplastik tehlikesi ve sürdürülebilirlik. Çevre Bilim ve Teknoloji Dergisi, Basım sayısı, 1, 171–197.

Yurtsever, M. (2019). Nano- ve Mikroplastik'lerin İnsan Sağlığı ve Ekosistem Üzerindeki Olası Etkileri. Memba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi, 5(2), 17–24.

Zhang, Z., Cui, Q., Chen, L., Zhu, X., Zhao, S., Duan, C., Zhang, X., Song, D., & Fang, L. (2022). A critical review of microplastics in the soil-plant system: Distribution, uptake, phytotoxicity and prevention. Journal of Hazardous Materials, 424, 127750. https://doi.org/https://doi.org/10.1016/j.jhazmat.2021.127750

EVALUATION OF TRANSITION EFFORTS OF TÜRKİYE TO ORGANIC AGRICULTURE: AN APPLICATION WITH THE MSD BASED RAWEC METHOD

Assoc. Prof. Dr. Semin TOPALOĞLU PAKSOY

Çukurova University, Faculty of Economics and Administrative Sciences, Department of Econometrics, Adana-Türkiye

ORCID ID: https://orcid.org/0000-0003-1693-0184

Dr. Emine Kokaçya DUVAN

Scientific Researcher, Kadirli/Osmaniye-Türkiye

ORCID ID: https://orcid.org/0000-0002-9180-9651

ABSTRACT

In recent years, the negative effects of industrial agriculture on the environment and health and the problems originating from climate change, in addition to the already emerging major problem of habitat loss, have led to an increase in global problems such as poverty, difficulty in accessing food, hunger and inadequate and/or unhealthy nutrition. These destructions demonstrate the importance and necessity of protecting ecological resources, necessary to continue food production in the future. Organic agriculture stands out as an alternative solution to these problems. Because organic agriculture is a form of agricultural production that does not harm human health and the environment and does not use chemical inputs in production. Therefore, it aims to produce high-quality and nutritious food that contributes to preventive health services and well-being. Therefore, the aim of the current study is to analyse Türkiye's performance in organic agriculture since the year 2019. Data for the period 2019-2023 was considered. The analysis is conducted using the RAWEC method, which is one of the MCDM methods. For the method, countries that have applied to become members of the EU are selected as alternatives and as the indicators; organic farming area, organic area share of total agricultural land, number of organic producers and processors, pesticide use per capita, and agricultural production use per value were determined. The analysis results show that there have no any changes in the rankings of candidate countries' performance for the period 2019-2023. While Türkiye maintains its first-place position in all years, its RAWEC score decreased the most in 2023 compared to 2019. Albania, while the country with the greatest performance improvement, has not made significant progress in changing its ranking. This situation highlights the need for candidate countries to embrace the organic production, and to allocate resources to all strategies and training to ensure compliance. Both the supply and demand for organic agriculture in our country must increase, and access to healthy food must be ensured and expanded. Turkey's efforts to adapt to EU norms in this regard will be a valuable opportunity to protect its ecology and develop its foreign trade.

Keywords: Organic agriculture, RAWEC method, modified standard deviation procedure, comparison analysis, performance evaluation

ÖZET

Son yıllarda, endüstriyel tarımın çevre ve sağlık üzerindeki olumsuz etkileri ve iklim değişikliğinden kaynaklı sorunlar, habitat kaybı olarak şimdiden ortaya çıkan büyük sorunun yanı sıra, küresel ölçekte karşılaşılan yoksulluk, gıdaya erişim zorluğu, açlık ve yetersiz ve/veya sağlıksız beslenme gibi sorunların giderek artmasına neden olmaktadır. Bu tahribatlar, gelecekte gıda üretimini devam ettirmede gerekli olan ekolojik kaynakları korumanın önemini ve gerekliliğini göstermektedir. Organik tarım bu sorunlara bir çözüm alternatifi olarak öne çıkmaktadır. Çünkü organik tarım, insan sağlığına ve çevreye zarar vermeyen ve üretimde kimyasal girdi kullanılmadan tarımsal üretim yapma biçimidir. Bu nedenle üretimde, koruyucu sağlık hizmetlerine ve refaha katkıda bulunan yüksek kaliteli ve besleyici gıda üretmeyi amaçlamaktadır. Bu nedenle mevcut çalışmanın amacı, Türkiye'nin organik tarım konusunda sergilediği performansı, 2019 yılından itibaren analiz etmektir. Analizde 2019-2023 dönemine ait veriler ele alınmıştır. ÇKKV yöntemlerinden biri olan RAWEC yöntemi ile yapılan analizlerde, alternatif olarak AB'ye üye olmak üzere başvuruda bulunmuş ülkeler; kriter olarak da bu ülkelere ait olan; Organik tarım alanı, Toplam tarım arazisinin organik alan payı, Organik üretici ve Organik işlemci sayısı, Kişi başına pestisit kullanımı ve Tarımsal üretimin değer başına kullanımı göstergeleri belirlenmiştir. Analiz sonuçları, 2019-2023 periyodunda aday ülke performanslarının sıralamalarında hiç bir değişikliğin olmadığını göstermektedir. Türkiye, birinci sıradaki konumunu korumakla birlikte, 2019 yılına göre 2023 yılında RAWEC skoru en fazla zayıflayan ülke olmuştur. Arnavutluk, performansını en fazla artıran ülke olmakla beraber sıralamasını değiştirebilecek bir ilerleme kaydedememiştir. Bu durum, aday ülkelerin organik üretim gibi güncel tarımsal üretim anlayışını benimsemesi ve bunlara uyulması konusunda her türlü strateji ve eğitime kaynak ayırması gerektiğini vurgulamaktadır. Organik tarım arzı kadar talebinin de ülkemizde artması, sağlıklı gıdaya erişimin sağlanması ve yaygınlaştırılması gerekmektedir. Türkiye'nin bu konuda AB normlarına adapte olmaya çaba sarf etmesi, sahip olduğu ekolojisini koruma ve dış ticaretini geliştirme açısından değerli bir fırsat olacaktır.

Anahtar Kelimeler: Organik tarım, RAWEC yöntemi, modifiye edilmiş standart sapma prosedürü, karşılaştırma analizi, performans değerlendirme

GİRİŞ

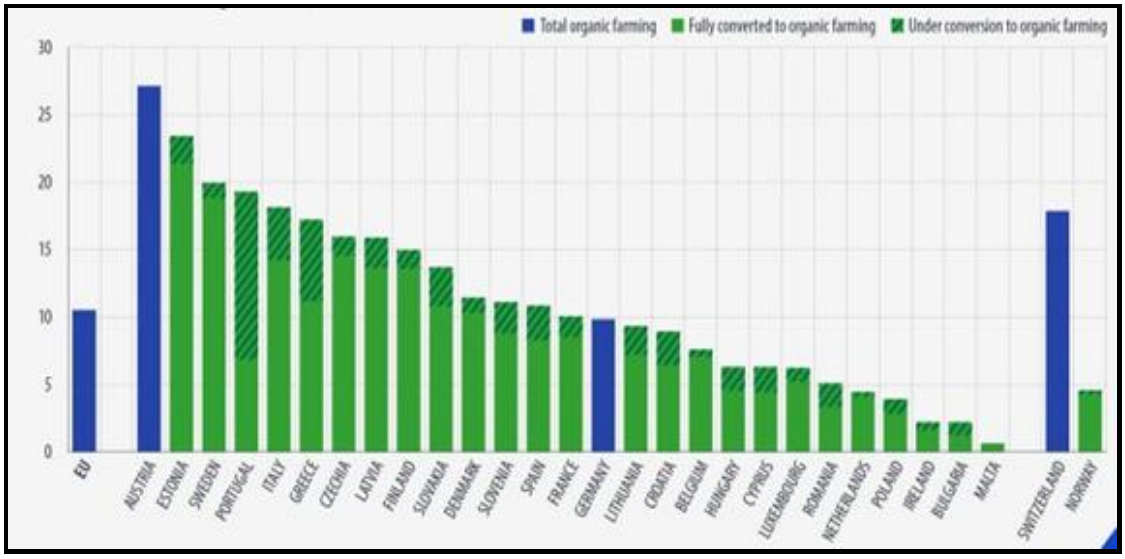
Organik tarım; toprakların, ekosistemlerin ve insanların sağlığını koruyan bir üretim sistemidir. Zira olumsuz etkileri olan girdileri kullanmak yerine, yerel koşullara uyarlanmış ekolojik süreçlere, biyoçeşitliliğe ve döngülere dayanmaktadır. Organik tarım; gelenek, yenilik ve bilimi bir araya getirerek tüm paydaşlar için adil ve faydalı ilişkiler sağlamaktadır (IFOAM General Assembly, 2008). Organik tarım ile toprak, bitki, hayvan, insan ve gezegenin sağlığı bir ve bölünmez bir bütün olarak ele alınmaktadır. Organik tarım, özellikle koruyucu sağlık hizmetlerine ve refaha katkıda bulunan yüksek kaliteli ve besleyici gıda üretmeyi amaçlamaktadır. Bu bağlamda, olumsuz sağlık etkileri olabilecek gübre, pestisit, hayvansal ilaç ve gıda katkı maddelerini kullanmaktan vazgeçilmelidir (IFOAM General Assembly, 2008). 2023 yılında tarımda kullanılan toplam pestisit miktarı 3,73 milyon ton aktif bileşend2 katı artık söz konusudur en oluşmakta olup, 2022'ye kıyasla %2 azalma olmuştur. Ancak, on yılda %14 artış, 1990 yılına kıyasla 2 katı olduğu görülmektedir (FAO, 2023).

Organik tarım gibi tarımda sürdürülebilir sistemler, büyüyen bir nüfus için sağlıklı, besleyici gıdalar ve diğer doğal ürünler üretmek açısından önemlidir. Aynı zamanda çiftçilerin adil bir yaşam sürmelerini, toprak verimlilik ve biyolojik çeşitliliği yenilemelerini ve artırmalarını, kıt su kaynaklarını korumalarını ve yenilemelerini, iklim değişikliğini azaltmalarını ve olumsuz

etkilenen insanların iklim değişikliğine uyum sağlamalarına ve daha dirençli hale gelmelerine yardımcı olurlar (IFOAM Organics International, 2025b).

Tüm dünya ülkelerinin pek çoğunda olduğu gibi Avrupa Birliğinde (AB) de organik tarıma önem verilmekte ve birlik ülkelerinin uyması için geliştirilen standartlar ve yaptırımlar ile güçlü bir şekilde desteklenmektedir (Çukur ve Işın, 2024). AB Ortak Tarım Politikası, tarımda çevresel, ekonomik ve sosyal sürdürülebilirliği sağlamak amacıyla tek Avrupa kıtası felsefesine uygun olarak geliştirilen bir politikadır (European Commission, 2020). Özellikle 2004 yılındaki AB genişleme sürecinde, Orta ve Doğu Avrupa ülkelerinin de birliğe katılmaları sonucunda, birlik üyeleri arasında ekonomik ve sosyal konular başta olmak üzere her alanda farklılıklar büyümüştür. Özellikle bu tarihten itibaren, artan farklılıkları ortadan kaldırmak amacıyla üye ülkelerden, geliştirilen ülke stratejileri doğrultusunda ilerleme kaydetmeleri ve sürdürülebilir kalkınma hedeflerine uyum sağlamaları beklenmektedir. Ayrıca, uyum çalışmalarında etkili ilerlemelerin sağlanması amacıyla üye ülkelerin 2024 yılı itibarıyla yıllık performans raporu sunmaları ve Komisyon ile yıllık inceleme toplantısı yaparak gerektiğinde specifik takip eylemleri talep edilecektir (European Commission, 2023).

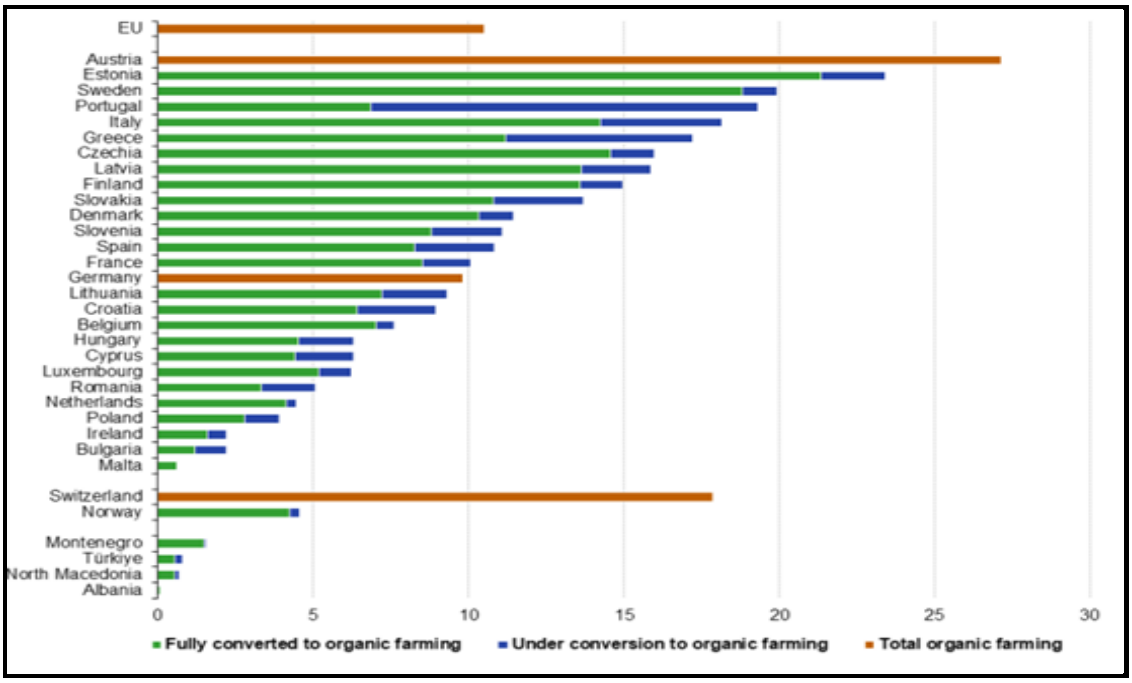
AB ülkelerinin, toplam tarım arazisinin organik alan payı bilgisi aşağıda Şekil 1 ile gösterilmektedir. Ekonomik olarak gelişmiş AB ülkelerinin bazılarının (Lüksemburg, Hollanda ve İrlanda gibi) AB ortalamasının altında kaldığı görülmektedir. Şekil 1'de pek çok üye ülkenin AB ortalaması üstünde tam organik tarımı yakaladığı, ancak 2004 genişleme sürecinde üye olan ülkelerin (Polanya, Romanya ve Malta gibi) bu seviyenin altında kaldığı; 2013 yılında birliğe üye olan Hırvatistan'ın ise AB ortalamasına yaklaşarak iyi performans sergilediği görülmektedir.



Şekil 1. AB üye ülkelerinde toplam tarım arazisinde organik tarım alan payı (2022)

Kaynak: Eurostat, 2024

Şekil 2'de yeşil renk, organik tarıma geçilmiş alanı; mavi renk organik tarıma geçilmekte olan alanı ve kırmızı renk organik tarıma tamamen geçilmiş alanları göstermektedir. Türkiye'nin ise AB üye ülkelerinin çok gerisinde olduğu ve aday ülkeler klasmanında yer aldığı görülmektedir. Avusturya ve İsviçre'nin tamamen organik tarıma geçen alanı çok yüksek olan ülkeler olarak öne çıktığı görülmektedir. Türkiye'nin ise Malta ve Kuzey Makedonya'nn önünde, sondan 3. sırada yer aldı görülmektedir.



Şekil 2. AB üye ve bazı aday ülkelerinin toplam tarım arazisinde organik tarım alanı payı (2022)

Kaynak: Eurostat, 2024.

Sürdürülebilir tarımsal gıda sistemlerini geliştirmek için Gıda ve Tarım Örgütü (FAO) ile stratejik ortaklığı bulunan IFAOM – Organics International'a göre dünya, küresel ölçekte yoksulluk, gıdaya erişim zorluğu ve hatta açlık ve yetersiz beslenme ile karşıya karşıya kalmıştır. Dünyada 800 milyondan fazla insan açlıkla karşı karşıya kalmakta ve yaklaşık 2 milyar insan yetersiz beslenmektedir. Küresel yetişkin nüfusun yaklaşık %30'u aşırı kilolu veya obez ve dünya çapında üretilen gıdanın yaklaşık %30'u da israf edilmektedir. İklim değişikliğinden kaynaklı sorunların yanı sıra endüstriyel tarımın çevre ve sağlık üzerindeki olumsuz etkileri ile doğa, insanlık tarihinde eşi benzeri görülmemiş ölçüde tahrip olmaya devam etmekte, ekilebilir alanlar azalmaktadır (IFOAM Organics International, 2025a). Bunların sonucu olarak çiftçilere makul bir gelir sağlayamama ve fosil yakıtlara yüksek derecede bağımlılık şeklinde ortaya çıkan sorunlar nedeniyle tarımda değişime olan ihtiyaç meydana gelmiştir. Ayrıca şimdi ve gelecekte gıda üretimi için gerekli olan ekolojik kaynakları korumanın gerekliliği zorunluluktur. Bu noktada organik tarım mevcut soruna bir çözüm alternatifi olarak öne çıkmaktadır.

Diğer taraftan AB komisyonu tarafından 2019 yılında kabul edilen Avrupa Yeşil Mutabakatı ile 2050 yılına kadar karbon-nötr hedefi sağlanmaya çalışılmaktadır. Mutabakatta sürdürülebilirliği, çok yönlü ve geniş bir şekilde geliştirilen ortak stratejilerin geliştirilmesi gerektiği prensibine dayanmaktadır. Tek bir kıtanın yalnız başına kurtarılamayacağı ve bu nedenle, özellikle ticarete yaptığı ve üye olmayan ülkelerin de bu felsefeye bağlı olması yönünde kararlar ile stratejik ortaklıkları benimsediği görülmektedir. Bu bağlamda, özellikle aday ülkeler başta olmak üzere AB ile ticaret yapan ülkeleri de kapsayan ve konuyla ilgili yaptırımların takip edilmesi ve uyum çabalarının artırılmasının önemi ortadır.

Bu çalışmada amaç, sürdürülebilirliğin önemli bir parçası olan organik tarımda, Türkiye'nin AB üye ve aday ülkeleri ile muhtemel farklılıkları ortaya çıkarmaya çalışmaktır. Bu bağlamda organik tarım ürünleri üretimi açısından önemli görülen ve erişilebilen değişkenler olarak;

organik tarım alanı, toplam tarım alanın içinde organik üretim yapılan alanın payı, organik tarım üretimi yapan üretici sayısı, organik tarım ürünleri işlemci sayısı, kişi başına düşen pestisit kullanımı ve tarımsal üretimin değer başına kullanımı değişkenleri dikkate alınarak Türkiye ve AB ülkelerinin performansları karşılaştırılmaktadır. Yapılan karşılaştırma ile Türkiye'nin organik tarıma yönelik çabası, objektif bir şekilde değerlendirilebilecektir. Ayrıca göreli olarak yeni bir ÇKKV metodu olan RAWEC yöntemi, bu alanda ilk kez uygulanarak literatüre katkı sağlanması beklenmektedir.

Veri ve Yöntem

Bu araştırmada kullanılan veri, Organik Tarım Araştırma Enstitüsü (Research Institute of Organic Agriculture (FiBL)) ve FAO (Food and Agricultural Organization) istatistik veri tabanından yararlanılmıştır. Çalışmanın yapıldığı dönemde en güncel veri 2023 yılına ait olduğundan, araştırmada 2019-2023 dönemine ait veriler ele alınmıştır. Çalışmada alternatif olarak belirlenen ülkeler Tablo 1, kriter olarak belirlenen değişkenler Tablo 2 ile gösterilmektedir. Çalışmada değişken ve ülkelerde veri kısıtı olmayan kayıtlara yer verilmiştir. Tablo 1'de de görüldüğü üzere Türkiye yaklaşık 40 yıl, Ukrayna ise yaklaşık 4 yıl önce üyelik başvurusu yapmıştır. Bu ülkeler en eski ve en yeni üyelik başvurusunda bulunan ülkeler olarak dikkat çekmektedir.

Tablo 1. AB 'ye aday ülkeler ve üyelik başvuru tarihleri

Ülkeler	***Üyelik Başvuru Tarihi***	***Adaylık Tarihi***	***Müzakerelere Başlama Tarihi***	***Fasıl Sayısı***
Arnavutluk	24 Nisan 2009	27 Haziran 2014	19 Temmuz 2022	-
Bosna - Hersek	15 Şubat 2016	15 Aralık 2022	-	-
Gürcistan*****	3 Mart 2022	14 Aralık 2023	-	-
Karadağ *****	15 Aralık 2008	17 Aralık 2010	29 Haziran 2012	33/3
Kuzey Makedonya	22 Mart 2004	15-16 Aralık 2005	19 Temmuz 2022	-
Moldova*****	3 Mart 2022	24 Haziran 2022	25 Haziran 2024	-
Sırbistan	22 Aralık 2009	1 Mart 2012	21 Ocak 2014	22/2
Türkiye	14 Nisan 1987	11 Aralık 1999	3 Ekim 2005	16/1
Ukrayna	28 Şubat 2022	24 Haziran 2022	25 Haziran 2024	-

*Eksik veri içeren ülkeler **Kaynak:** TC. Dışişleri Bakanlığı (2025).

Tablo 2. Kriter olarak kullanılan değişkenler

Değişken Kodu	**Değişken Açıklaması**	**Birim**
X1	Organik tarım alan	ha
X2	Toplam tarım arazisinin organik alan payı	%
X3	Organik üretici sayısı	Kişi sayısı
X4	Organik işlemci sayısı	Kişi sayısı
X5	Kişi başına pestisit kullanımı	Kg/kişi
X6	Tarımsal üretimin değer başına kullanımı	g/Int$[1]

[1] Toplam üretim miktarı (gr) / Toplam üretim değeri (uluslararası $)

Kaynak: statistics.fibl.org ve fao.org

Modifiye Edilmiş (Değiştirilmiş) Standart Sapma (Modified Standard Deviation -MSD) Prosedürü

Puška vd. (2022) tarafından geliştirilen MSD prosedürü, standart sapma (SD) tekniğinin bir uzantısıdır. SD yaklaşımına iki adım eklenmiştir. İlk adım, sütun toplamını hesaplamaktır. İkinci adım, standart sapma değerini bu göstergeye göre düzeltmektir. Bu prosedür aşağıdaki adımları içermektedir (Puška vd. 2022; Akbulut ve Aydın, 2024):

Adım 1. Karar matrisinin oluşturulması. Karar matrisi Y, Eşitlik (1) ile gösterildiği şekilde oluşturulmaktadır. Matriste m; alternatifleri, n ise kriter sayılarını ifade etmektedir. The decision matrix (Y) is prepared as in Eq. (1). This matrix includes m alternatives, K1,…,Km based on the n criteria, D1,…, Dn.

Y= $\left[y_{ij}\right]_{mxn}$ y_{ij}: i. alternatifin j. kriter altındaki değeridir. (1)

Adım 2. Y matrisi, kriterlerin fayda ve maliyet özellikleri göz önünde bulundurularak, Eşitlik (2) ve (3) yardımıyla normalleştirilmektedir.

$$V_{ij}= \frac{y_{ij}}{\max\{y_{ij}|i=1,2\ldots m\}}$$ fayda kriterleri için (2)

$$V_{ij}= \frac{\min\{y_{ij}|i=1,2\ldots m\}}{y_{ij}}$$ maliyet kriterleri için (3)

Adım 3. Her kriterin standart sapması (σ_n) hesaplanmaktadır.

Adım 4. Sütunların toplamının toplamı hesaplanmaktadır.

Adım 5. Standart sapmanın modifiye edilmiş (düzeltilmiş) değeri, Eşitlik (4) yardımıyla hesaplanmaktadır.

$$\sigma' = \frac{\sigma}{\sum_j^n y_{ij}} \quad (4)$$

Adım 6. Kriterlerin nihai ağırlıkları Eşitlik (5) yardımıyla hesaplanmaktadır.

$$w_j^{MSD} = \frac{\sigma_j'}{\sum_{j=1}^n \sigma_j'} \quad (5)$$

RAWEC Yöntemi

Çok kriterli karar verme (ÇKKV) yöntemlerinden biri olan RAWEC yöntemi, Puška vd.(2024) tarafından literatüre kazandırılan ve hayli yeni olan bir yöntemdir (Akbulut ve Aydın, 2024). Diğer birçok ÇKKV yaklaşımıyla karşılaştırıldığında basit, uygulanması kolay ve etkilidir. Yöntem, çift normalizasyona ve ideal ve anti-ideal değerlerden sapmaların hesaplanmasına dayanmaktadır. Bu yöntem aşağıda verilen işlem adımlardan oluşmaktadır (Puška vd, 2024).

Adım 1. Problemin Eşitlik (1) ile gösterilen karar matrisi oluşturulmaktadır.

Adım 2. Normalleştirilmiş karar matrisi, Eşitlik (6) ve (7) uygulanarak oluşturulmaktadır. Eşitliklerde de gösterildiği üzere karar matrisinin normalleştirilmesinde, çift normalizasyon işlemi uygulanmaktadır.

$$V_{ij}= \frac{y_{ij}}{\max\{y_{ij}|i=1,2\ldots m\}} \text{ ve } V'_{ij}= \frac{\min\{y_{ij}|i=1,2\ldots m\}}{y_{ij}} \text{ fayda kriteri için} \quad (6)$$

$$V_{ij}= \frac{\min\{y_{ij}|i=1,2\ldots m\}}{y_{ij}} \text{ ve } V'_{ij}= \frac{y_{ij}}{\max\{y_{ij}|i=1,2\ldots m\}} \text{ maliyet kriteri için} \quad (7)$$

Adım 3. Kriter ağırlığından sapmayı elde etmek için denklem (8) ve (9) uygulanmaktadır.

$n_{ij}= \sum_{i=1}^{m} w_j \ .(1- V_{ij})$, w_j; j. kriter ağırlığıdır. (8)

$n'_{ij}= \sum_{i=1}^{m} w_j \ .(1- V'_{ij})$ (9)

Adım 4. Her alternatife ait Ω_i değeri Eşitlik (10) yardımıyla hesaplanmaktadır.

$$\Omega_i = \frac{n'_{ij}-n_{ij}}{n'_{ij}+n_{ij}} \quad (10)$$

RAWEC yönteminde $\Omega_i \in [-1,1]$ 'dir. En yüksek Ω_i değerine sahip i. alternatif, en iyi alternatifi göstermektedir.

BULGULAR

Analizde ilk aşamada MSD prosedüründen yararlanılarak her yıl için kriterlerin ağırlıkları hesaplanmıştır. Tablo 3'de 2019-2023 yıllarına ait kriter ağırlıkları gösterilmekte ve ağırlıkların genel olarak her yıl için 0,14-0,20 aralığında yer aldığı görülmektedir. Tüm yıllarda X1 kriterinin en yüksek, X6 kriterinin en düşük önem derecesine sahip olduğu görülmektedir. X2, X3 ve X4 kriterlerinin hemen hemen birbirine yakın önem derecelerine sahip olduğu dikkat çekmektedir.

Tablo 3. Yıllara göre kriter ağırlıkları

Ağırlıklar	X1	X2	X3	X4	X5	X6
$W_j^{MSD-2019}$	0,20	0,17	0,17	0,17	0,15	0,14
$W_j^{MSD-2020}$	0,20	0,17	0,17	0,17	0,15	0,15
$W_j^{MSD-2021}$	0,20	0,16	0,18	0,15	0,16	0,15
$W_j^{MSD-2022}$	0,20	0,17	0,17	0,16	0,16	0,15
$W_j^{MSD-2023}$	0,19	0,16	0,17	0,17	0,16	0,15

Ağırlıkların hesaplanmasından sonra, RAWEC yönteminin işlem adımları uygulanarak kriterler ve hesaplanan ağırlıkları ile ülkeler değerlendirilerek her yıl için RAWEC skorları hesaplanmaktadır. Ülkelerin yıllara göre RAWEC skorlarları (Ωi), Tablo 4'de gösterilmektedir.

Tablo 4. Yıllara göre RAWEC skorları (Ω_i) ve sıralamaları

Ülkeler	Ω_i	$Rank_{2019}$	Ω_i	$Rank_{2020}$	Ω_i	$Rank_{2021}$	Ω_i	$Rank_{2022}$	Ω_i	$Rank_{2023}$
Arnavutluk	-0,60	6	-0,54	6	-0,40	6	-0,54	6	-0,39	6
Bosna Hersek	-0,26	5	-0,21	5	-0,31	5	-0,21	5	-0,24	5
Kuzey Makedonya	-0,06	4	0,03	4	-0,08	4	0,03	4	-0,07	4
Sırbistan	0,00	3	0,07	3	0,05	3	0,07	3	0,03	3
Türkiye	0,60	1	0,57	1	0,45	1	0,57	1	0,42	1
Ukrayna	0,12	2	0,13	2	0,18	2	0,13	2	0,15	2

Sıralamada ilk 3'de yer alan ülkeler; Türkiye, Ukrayna ve Sırbistan'dır. Bu ülkelerin tüm periyod boyunca pozitif, diğerlerinin negatif RAWEC skorlara sahip olduğu görülmektedir. Tüm periyot boyunca en düşük skorları ile 6. sırada yer alan ve istikrarlı bir şekilde RAWEC skorunu artırma trendinde olan tek ülke Arnavutluk'tur. Diğer tüm ülkelerin inişli çıkışlı skorlara sahip olduğu, buna rağmen sıralamadaki konumlarının değişmediği görülmektedir. Bu durum, ülkelerin RAWEC skorları ile kayda değer ilerlemeler sergilemediği ve organik tarıma hak ettiği önemi yeterince vermediğinin bir işareti olarak yorumlanabilir.

SONUÇ ve ÖNERİLER

Analiz sonuçları, 2019 yılından 2023 yılına kadar aday ülke performanslarının sıralamalarında hiç bir değişikliğin olmadığını göstermektedir. Türkiye, birinci sıradaki konumunu korumakla birlikte, 2019 yılına göre 2023 yılında performansı en fazla zayıflayan ülke olmuştur. Arnavutluk performansını en fazla artıran ülke olmakla beraber sıralamasını değiştirebilecek bir ilerleme kaydedememiştir. Bu durum, aday ülkelerin organik üretim konusunda gerek yaptırımlar gerekse bunlara uyulması konusunda her türlü strateji ve eğitime kaynak ayırması, bu konuda AB normlarına adapte olmaya çaba sarf etmesi ekolojiyi koruması ve dış ticaretini geliştirmesi açısından faydalı olacaktır. Özellikle tarımda modern teknolojilere erişimin olmadığı veya zayıf olduğu AB'ye aday olan bu ülkelerde, organik tarımın yaygınlaştırılması, yerel kaynakların optimum kullanılmasına katkı sağlama potansiyeli oluşturacaktır.

Diğer taraftan, iklim krizi aşırı hava dalgalanmalarına sebep olmakta ve giderek tarım için artan bir tehdit oluşturmaktadır. Oysa organik sistemlerin, şiddetli kuraklık ve sel gibi stres koşullarında geleneksel sistemlerle karşılaştırıldığında, iklim değişikliğine karşı daha istikrarlı ve dirençli olduğu görülmektedir. Bu nedenle ülkelerin organik tarım alanında sergiledikleri performansı artırmaları, gerek üretici gerekse tüketiciler açısından fayda sağlayacaktır. Aynı zamanda sağlığının korunması, çevre kirliliğinin önlenmesi gibi faydalı etkileri en büyük kazanç olacaktır. Bu nedenle ülkelerin tarım politikalarında organik tarıma dönüşüm stratejilerini belirlemeleri ve gerekli teşvikleri sağlayarak çiftçilerin organik üretim yapmaları sağlamaları gerekmektedir. Türkiye'nin de, ABD de 1970'de AB üye ülkelerinde 1975-1980 yıllarında başladıkları adaptasyon düzenlemelerini (FAO, 2025), daha fazla gecikmeden çıkarıp uygulamaya başlaması gerekmektedir.

KAYNAKÇA

Akbulut, O. Y. & Aydın, Y. (2024). A hybrid multidimensional performance measurement model using the MSD-MPSI-RAWEC model for Turkish banks. *Journal of Mehmet Akif Ersoy*

University Economics and Administrative Sciences Faculty, 11(3), 1157- 1183. https://doi.org/10.30798/makuiibf.1464469

Çukur, T. & Işın, F. (2024). Bazı Avrupa Birliği ülkelerinin organik tarım performanslarının TOPSIS yöntemiyle değerlendirilmesi, *Turkish Journal of Agricultural Economic*, 30(2): 99-109. https://doi.org/10.24181/tarekoder.1491857

European Commission. (2020), EU Agriculture in numbers performance on the nine spesific objectives of the CAP, Agricultural and Rural Development, May 2020. https://agriculture.ec.europa.eu/system/files/2020-05/analytical-factsheet-eu-level_en_0.pdf. Erişim tarihi: 28 Mayıs 2024.

European Commission. (2023), Agricultural and Rural Development, the common agricultural policy: 2023-27. https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27_en. Erişim tarihi: 28 Mayıs 2024.

Eurostat. 2024. Developments in organic farming. In: Eurostat. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Developments_in_organic_farming Erişim tarihi: Temmuz, 2025

FAO (2023). Pesticides use and trade, 1990-2023 https://openknowledge.fao.org/items/3251bdcf-888c-40ab-8223-b135cebfe91e Erişim tarihi: 26.10.2025

FAO (2025). General concepts and issues in organıc agriculture. https://www.fao.org/4/y4137e/y4137e01.htm, Erişim tarihi: 2.11.2025

IFOAM General Assembly, (2008). Definition of organic agriculture. https://www.ifoam.bio/why-organic/organic-landmarks/definition-organic, Erişim tarihi: 25.10.2025

IFOAM Organics International. (2025a). The principle of health. https://www.ifoam.bio/why-organic/principles-organic-agriculture/principle-health, Erişim tarihi: 25.10.2025

IFOAM Organics International. (2025b). Strategic Plan 2017-2025 for IFOAM – Organics International. strategic_plan_v03.pdf Erişim tarihi: 26.10.2025

Puška, A., Stević, Ž., & Pamučar, D. (2022). Evaluation and selection of healthcare waste incinerators using extended sustainability criteria and multi-criteria analysis methods. Environment, *Development and Sustainability*, 1-31. https://doi.org/10.1007/s10668-021-01902-2

Puška, A., Štilić, A., Pamučar, D., Božanić, D., & Nedeljković, M. (2024). Introducing a Novel multi-criteria Ranking of Alternatives with Weights of Criterion (RAWEC) model. MethodsX, 102628. https://doi.org/10.1016/j.mex.2024.102628

TC. Dışişleri Bakanlığı (2025). Bir bakışta Avrupa, Avrupa Birliğinin genişlemesi, Aday ülkeler. https://www.ab.gov.tr/aday-ulkeler_265.html Erişim tarihi: 23.10.2025

THE STUDIES ON BOSCALID-RESISTANCE IN *ALTERNARIA* SPP. IN PLANT PROTECTION

Prof. Dr. Aysun CAVUSOGLU

Kocaeli University, Faculty of Agriculture, Department of Plant Protection, 41285, Kocaeli, Türkiye

Prof. Dr. Mehmet Erhan GÖRE

Bolu Abant İzzet Baysal University, Faculty of Agriculture, Department of Plant Protection, 14030, Bolu, Türkiye

ABSTRACT

Boscalid is an active substance as a fungicide, a member of the succinate dehydrogenase inhibiting (SDHI) group in the Fungicide Resistance Action Committee (FRAC) list, and is frequently used in spraying programs in crop protection against Ascomycota members such as *Alternaria* spp.. Resistance towards the active ingredient is an emerging problem in *Alternaria* populations via mutations in some crop cultivars. The *Alternaria* genus includes numerous phytopathogen species that affect a wide range of crops. *Alternaria* spp. are predominantly recognized as necrotrophic pathogens responsible for diseases like early blight, brown spot, leaf and fruit lesions, and necrosis of various plant parts, including underground storage organs. These pathogens, which are mostly anamorphic members of the Ascomycota phylum, exhibit a wide geographical distribution and substantial host diversity. It appears that these studies, on the emerging problem of boscalid-resistance in *Alternaria* spp. in different commercial crops, are beginning to increase. Boscalid resistance issues against the disease, *Alternaria* spp., in plants such as *Solanum lycopercicum*, and *S. tuberosum*, which are members of the Solanaceae family, *Vaccinium* spp., which are members of the Ericaceae family, and *Pistacia vera*, which is a member of the Anacardiaceae family, which are exposed to *Alternaria* spp., have been studied and proven in the scientific field. These studies were conducted *in vitro* and/or *in vivo* environments to evaluate the results of using boscalid alone or in combination with other active substances. In this review article, information about these studies is compiled, the importance of the subject is emphasized, and attention is drawn to the issue of Boscalid resistance.

Keywords: *Alternaria* spp., boscalid, fungal pathogens, resistance

INTRODUCTION

With the increase in the world population, there has been a transition from small production areas to intensive commercial production areas, and the previously used handmade organic or inorganic chemicals have been replaced by intensively used and commercially produced pesticides. One of the most used pesticide groups is fungicides.

From the point of view of fungicides, copper sulphate, sulphur, mercurous chloride, etc. were the most well-known active substances until the 1940s, but after the 1940s, active substances such as thiram, captan, dodine, etc. came into use. As we approach the present day, especially

in the last 50 years, active ingredients such as iprodione, carbendazim, metalaxyl, etc. have taken their place in the market and have begun to be used extensively (Beckerman et al., 2023; Russel, 2005).

Excessive use of some of the fungicides, at inappropriate times, and using inappropriate methods has ultimately led to resistance problems. In fact, mutations introduced by the pathogen in the affected target area or the changes in the pathogen population play crucial roles in this problem. For all these reasons, resistance to lots of active ingredients has occurred in the combat against fungal diseases seen in many plant species (Grabke et al., 2014; Hu et al., 2015; Lucas et al., 2015 Wang et al., 2022).

Fungi are found in plants as pathogens, besides being saprophytes, and endophytes. The most important issue in plant production is to overcome phytopathological problems and protect the crops with sustainable methods. However, due to many reasons stated above, sustainability may not be possible in the use of a product obtained as a result of many research and development studies (Abubakar et al., 2020; Beckerman et al., 2023).

The *Alternaria* genus has also phytopathogenic species as members of the Ascomycota phylum and affects dozens of commercially important plant groups. Many organic and inorganic active substances have been identified against *Alternaria* spp., boscalid being one of them. Boscalid is also an active substance that has been obtained and tested as a result of many studies. Boscalid is also now facing resistance issues in some plants to the plant pathogen, which is associated with *Alternaria* diseases. This review article will address the issue of boscalid resistance in commercially produced plants suffering from the pathogens *Alternaria* spp..

CHARACTERISTICS AND USES OF BOSCALID

Boscalid controls a broad range of phytopathogenic fungi in cultivated plants via inhibition of fungal development. The inhibited development stages are germ tube elongation, appressoria formation, and mycelial growth. The active ingredient is transported via translaminar and acropetal ways (Stammler et al., 2008). Boscalid was registered in Chile, Korea, the UK in 2002, and the USA in 2002 (Anonymous, 2025a).

Boscalid is an active substance as a fungicide, a member of the SDHI group in the Fungicide Resistance Action Committee (FRAC) list (FRAC, 2025), and is frequently used in spraying programs in crop protection against Ascomycota members. Boscalid was registered alone with 50% active ingredient to control *Penicillium* spp., *Botrytis cinerea*, *Monilia fructigena*, *Alternaria alternata* f. sp. *citri* in apple, pistachio, tangerine, and grape. In addition, boscalid usage is registered in combination with other substances to control *Erysiphe corylacearum*, *Sphaerotheca macularis*, *Leveillula taurica*, *Puccinia porri*, etc. in hazelnut, vegetables, strawberry, etc. in Türkiye (Anonymous, 2025b), and in some of the other countries (Anonymous, 2025c; Anonymous, 2025d).

Before resistance studies, there were numerous studies about the boscalid effects on fungal diseases on crop protection. In a study on the sensitivity of *Botrytis cinerea* from vegetables to boscalid in a greenhouse (Zhang et al., 2007), it was found out that boscalid inhibited mycelial growth and conidial germination in appropriate and over-doses. In addition, the study emphasized that resistance was lower than for prymethanil. Secondly, synergism between boscalid and kresoxim-methyl was pointed out. Another study was about boscalid effects on *Sclerotinia sclerotiorum* isolates in oilseed rape and beans to observe differences in sensitivity on the isolates from boscalid-treated fields or not treated fields (Stammler et al., 2007). The results indicated that the frequency distribution of the ED50 values was similar for both types of isolates. In a study on boscalid and fluazinam treatment for controlling *Sclerotinia minor* in

peanuts was shown that the fungicides are effective when applied before infection (Smith et al., 2008). *Penicillium digitatum* is an important pathogen at the post-harvest stage in citrus. Boscalid was applied to 189 isolates of the pathogen and the results indicated that the active substance has fungicidal action against *P. digitatum* in the study (Xu et al., 2020). These studies show that the active ingredient boscalid has a place and value in crop protection against fungal diseases.

CHARACTERISTICS OF THE *ALTERNARIA* SPP. AND ITS DAMAGES TO PLANTS

The species belonging to the genus *Alternaria* hold particular importance due to their wide host range and capacity to cause significant damage both economically and ecologically among fungal plant pathogens. These pathogens can induce diseases such as stem cankers, tuber decay, leaf blight, seed necrosis, and fruit rot in a variety of crop species (Goetz & Dugan, 2006; Adongo et al., 2015; Matić et al., 2020).

The cultivated plant families, such as Apiaceae, Cucurbitaceae, Ericaceae, Fabaceae, Rosaceae, Rutaceae, Solanaceae, etc., represent major groups affected by *Alternaria* spp.. These crops occupy large global cultivation areas and contribute significantly to global food security (FAOSTAT, 2025). Consequently, understanding protection and remedy methods against *Alternaria* in cultivated plant families is of critical importance for plant protection efforts worldwide.

In the last decades, lots of studies have demonstrated that different *Alternaria* spp. can be pathogens in various crops. For example, *Alternaria jingzhouensis* was found on leaves of *Citrullus lanatus*, and *A. momordicae* was found on *Momordica charantia* leaves as weak pathogens, but these were highly pathogenic on some other cucurbits (Aung et al., 2024). In a study on cucurbit leaf spot, *Alternaria alternata*, *A. arborescens*, and *Curvularia* sp. were found in different degrees of pathogenicity (Paredes-Machado et al., 2025). Nanofungicides with selenium and silicon were applied against *Alternaria alternata*, which is a pathogen in *Phaseolus vulgaris* L. (Taha et al., 2023).

Anwaar et al. (2020) evaluated the effects of some fungicides and biopesticides for the control of *Alternaria citri* in citrus, which causes black necrotic lesions on branches, young leaves, and fruits. The Apiaceae family also has an important role as a source of vegetables and aromatic plants. Bessadat et al. (2025) found that new species of the *Alternaria* genus and, emphasized that the family can be a reservoir for the *Alternaria* genus.

The conclusion emerging from these studies is that *Alternaria* spp. can be found in many plant families, and new species within the families have been identified day by day. In addition to identifying the pathogen species, these studies also address preventative and control measures.

BOSCALID RESISTANCE IN THE COMBAT AGAINST *ALTERNARIA* SPP.

Resistance mechanisms for the SDHI group have been studied among phytopathogen fungi such as *Aspergillus* sp., *Botrytis cinerea*, *Didymella* sp, *Blumeriella* sp., *Fusarium* sp., *Erysiphe* sp., etc., and well documented in a review articles (Yin et al., 2023; Kovacevik et al., 2025). Although not many years have passed since the introduction of boscalid to the market, studies on its resistance or sensitivity to *Alternaria* spp. have begun.

Alternaria alternata is one of the main pathogens on medicinal plant *Fritillaria thunbergii*, and the main protection method is the use of chemical fungicides in China. Procymidone resistance occurred in the main growing fields in recent years, and research showed that the resistance

caused a cross-resistance between the active ingredient and iprodione and between boscalid and pydiflumetofen. In addition, four types of mutations were found in boscalid-resistant isolates (Wang et al., 2025).

Boscalid resistance has been studied by Avenot et al. (2008; 2014) and Avenot & Michailides (2020) for *Alternaria alternata* in pistachio orchards. The boscalid resistance at different levels, SDHD mutations in *Alternaria* sp., cross or multiple resistance between the other applied active ingredients, and rapid development in *Alternaria* sp. resistance to boscalid were indicated in the studies.

Blueberry species are popular due to their health benefits and their taste. *Alternaria* fruit rot is one of the postharvest problems affecting the yield. The growers chose fungicide application before harvest in crop protection to overcome the disease. In a study seven fungicides, including boscalid, were assessed for fungicide resistance profiles. The results showed that nineteen of forty-three *Alternaria alternata* isolates were resistant to boscalid (Beg et al., 2025). In addition, one *A. tenuissima* and one *A. limoniasperae* isolate were found resistant to boscalid.

Prunus dulcis is an important fruit and is affected by *Alternaria* spp. in late spring or early summer. Boscalid resistance was assessed from 520 isolates of *A. alternata*. 204 of them found resistance to boscalid, and they showed that the resistance developed within a short time after its registration for almonds. They emphasized that applications of other fungicides in different modes of action in mixed or rotated ways can be a management method for the disease (Förster et al., 2022).

Broccoli seeds can be infected naturally by *Alternaria brassicicola*, and the isolates of the pathogen showed reduced sensitivity to azoxystrobin in a study (Kaur et al., 2025). In continuation of the study, nine of the fifty-eight isolates of the pathogen showed reduced sensitivity to the SDHI group fungicides, boscalid and penthiopyrad, in broccoli seeds.

At the same time, the boscalid resistance or reduced sensitivity to *Alternaria* spp. has been studied in other crops such as strawberries (Li et al., 2025), tomatoes (Shi et al., 2015), and potatoes (Kokaeva et al., 2025), etc. Within the scope of the present review, the boscalid resistance was associated with the SDHI resistance mutations, cross or multiple resistance in fungicides that share the same group, location of pathogens, or differences in the pathogen species.

REFERENCES

Abubakar, Y., Tijjani, H., Egbuna, C., Adetunji, C. O., Kala, S., Kryeziu, T. L., ... & Patrick-Iwuanyanwu, K. C. (2020). Pesticides, history, and classification. In *Natural remedies for pest, disease and weed control* (pp. 29-42). Academic Press. DOI: 10.1016/B978-0-12-819304-4.00003-8

Adongo, B. A., Kwoseh, C. K., & Moses, E. (2015). Storage rot fungi and seed-borne pathogens of onion. *Journal of Science and Technology (Ghana), 35*(2), 13-21. DOI: 10.4314/just.v35i2.2

Anonymous (2025a). Pesticide Properties Database. "Boscalid". University of Hertfordshire. https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/86.htm (Retrieved; October, 28, 2025).

Anonymous (2025b). Plant Protection Database. https://bku.tarimorman.gov.tr (Retrieved; October, 28, 2025).

Anonymous (2025c). List of registered plant protection products. https://fis.mps.hr/fis/javna-trazilica-szb/ (Retrieved; October, 28, 2025).

Anonymous (2025d). European Comission Pesticides Database. https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database (Retrieved; October, 28, 2025).

Anwaar, H., Iqbal, Z., Rehman, M. A., Mubeen, M., Abbas A., Usman, H. M., ... & Sajjad, K. (2020). Evaluation of fungicides and biopesticides for the control of Alternaria black rot disease in citrus. *Plant Cell Biotechnology and Molecular Biology*, *21*, 118-126.

Avenot, H., Morgan, D. P., & Michailides, T. J. (2008). Resistance to pyraclostrobin, boscalid and multiple resistance to Pristine® (pyraclostrobin+ boscalid) fungicide in *Alternaria alternata* causing alternaria late blight of pistachios in California. *Plant Pathology*, *57*(1), 135-140. DOI: 10.1111/j.1365-3059.2007.01701.x

Avenot, H. F., Van Den Biggelaar, H., Morgan, D. P., Moral, J., Joosten, M., & Michailides, T. J. (2014). Sensitivities of baseline isolates and boscalid-resistant mutants of *Alternaria alternata* from pistachio to fluopyram, penthiopyrad, and fluxapyroxad. *Plant Disease*, *98*(2), 197-205. DOI: 10.1094/PDIS-04-13-0459-RE

Avenot, H. F., & Michailides, T. J. (2020). Occurrence and extent of boscalid resistance in populations of *Alternaria alternata* from California pistachio orchards. *Plant Disease*, *104*(2), 306-314. DOI: 10.1094/PDIS-04-19-0699-SR

Aung, S. L. L., Liu, F. Y., Gou, Y. N., Nwe, Z. M., Yu, Z. H., & Deng, J. X. (2024). Morphological and phylogenetic analyses reveal two new *Alternaria* species (Pleosporales, Pleosporaceae) in Alternaria section from Cucurbitaceae plants in China. *MycoKeys*, *107*, 125-139. DOI: 10.3897/mycokeys.107.124814

Beckerman, J., Palmer, C., Tedford, E., & Ypema, H. (2023). Fifty years of fungicide development, deployment, and future use. *Phytopathology*, *113*(4), 694-706. DOI: 10.1094/PHYTO-10-22-0399-IA

Beg, M. A., Aktaruzzaman, M., Lewis, K. J., & Oliver, J. E. (2025). Fungicide resistance profiles of *Alternaria* spp. associated with fruit rot of blueberry in Georgia, USA. *Frontiers in Plant Science*, *16*, 1524586. DOI: 10.3389/fpls.2025.1524586

Bessadat, N., Bataillé-Simoneau, N., Colou, J., Hamon, B., Mabrouk, K., & Simoneau, P. (2025). New members of *Alternaria* (Pleosporales, Pleosporaceae) collected from Apiaceae in Algeria. *MycoKeys*, *113*, 169. DOI: 10.3897/mycokeys.113.138005

FAOSTAT. (2025). Food and Agriculture Organization of the United Nations, Statistics Database. https://www.fao.org/faostat (Retrieved; October, 28, 2025).

Förster, H., Luo, Y., Hou, L., & Adaskaveg, J. E. (2022). Mutations in *Sdh* gene subunits confer different cross-resistance patterns to SDHI fungicides in *Alternaria alternata* causing Alternaria leaf spot of almond in California. *Plant Disease*, *106*(7), 1911-1918. DOI: 10.1094/PDIS-09-21-1913-RE

FRAC (2025). Fungicide Resistance Action Committee. https://www.frac.info/ (Retrieved; October, 28, 2025).

Goetz, J., & Dugan, F. M. (2006). *Alternaria malorum*: a mini-review with new records for hosts and pathogenicity. *Pacific Northwest Fungi*, *1*(3), 1-8.

Grabke, A., Fernández-Ortuño, D., Amiri, A., Li, X., Peres, N. A., Smith, P., & Schnabel, G. (2014). Characterization of iprodione resistance in *Botrytis cinerea* from strawberry and blackberry. *Phytopathology*, *104*(4), 396-402. DOI: 10.1094/PHYTO-06-13-0156-R

Hu, M. J., Grabke, A., Dowling, M. E., Holstein, H. J., & Schnabel, G. (2015). Resistance in *Colletotrichum siamense* from peach and blueberry to thiophanate-methyl and azoxystrobin. *Plant Disease*, *99*(6), 806-814. DOI: 10.1094/PDIS-10-14-1077-RE

Kaur, N., Malik, A. A., Cerritos-Garcia, D. G., Koch Bach, R. A., Everhart, S., & Dutta, B. (2025). Cross-resistance in *Alternaria brassicicola* from naturally infested broccoli seeds against two succinate dehydrogenase inhibitor fungicides. *Applied and Environmental Microbiology*, 91(10) e01083-25. DOI: 10.1128/aem.01083-25

Kokaeva, L., Berezov, A., Pobedinskaya, M., Balabko, P., & Elansky, S. (2025). Assessing boscalid efficacy and resistance in large-spored Alternaria pathogens of potato and tomato crops. *Journal of Plant Diseases and Protection*, *132*(3), 91. DOI: 10.1007/s41348-025-01086-1

Kovacevik, B., Mitrev, S., Arsov, E., Markova Ruzdik, N., Todevska, D., & Trajkova, F. (2025). The Succinate Dehydrogenase Inhibitor Fungicides: Fungal Resistance and its Management. *Journal of Agriculture and Plant Sciences*, *23*(1), 41-54. DOI: 10.46763/JAPS2523141k

Li, T., Yu, W., Feng, J., Mao, C., Yu, H., Liu, A., & Zhang, C. (2025). Resistance of *Alternaria* spp. Causing Strawberry Black Spot to Boscalid in China. *Plants*, *14*(13), 1941. DOI: 10.3390/plants14131941

Lucas, J. A., Hawkins, N. J., & Fraaije, B. A. (2015). The evolution of fungicide resistance. *Advances in Applied Microbiology*, *90*, 29-92. DOI:10.1016/bs.aambs.2014.09.001

Matić, S., Tabone, G., Garibaldi, A., & Gullino, M. L. (2020). Alternaria leaf spot caused by *Alternaria* species: an emerging problem on ornamental plants in Italy. *Plant Disease*, *104*(8), 2275-2287. DOI: 10.1094/PDIS-02-20-0399-RE

Paredes-Machado, C., Bogaj, V., Balazs, G., & Papp, D. (2025). *Alternaria* and *Curvularia* leaf spot pathogens show high aggressivity on watermelon, and are emerging pathogens in cucurbit production. *Phytopathologia Mediterranea*, *64*(1), 41-55. DOI: 10.36253/phyto-15955

Russell, P. E. (2005). A century of fungicide evolution. *The Journal of Agricultural Science*, *143*(1), 11-25. DOI: 10.1017/S0021859605004971

Shi, X. J., Ren, L., Song, Y. Q., Han, J. C., Liu, H. P., & Zhang, Y. J. (2015). Sensitivity of *Alternaria solani* to boscalid and control of boscalid resistance with commonly-used fungicides in Shanxi, China. *Australasian Plant Pathology*, *44*(3), 327-334. DOI: 10.1007/s13313-015-0352-9

Smith, D. L., Garrison, M. C., Hollowell, J. E., Isleib, T. G., & Shew, B. B. (2008). Evaluation of application timing and efficacy of the fungicides fluazinam and boscalid for control of Sclerotinia blight of peanut. *Crop Protection*, *27*, 823-833. DOI: 10.1016/j.cropro.2007.11.010

Stammler, G., Benzinger, G., & Speakman, J. (2007). A rapid and reliable method for monitoring the sensitivity of *Sclerotinia sclerotiorum* to boscalid. *Journal of Phytopathology*, *155*(11-12), 746-748. DOI: 10.1111/j.1439-0434.2007.01294.x

Stammler, G., Brix, H. D., Nave, B., Gold, R., & Schoefl, U. (2008). Studies on the biological performance of boscalid and its mode of action. Modern fungicides and antifungal compounds V: 15th International Reinhardsbrunn Symposium, Friedrichroda, Germany, May 6-10, 2007, (Ed. H. W. Dehne, H. B. Deising, U. Gisi, K. H. Kuck, P. E. Russell, H. Lyr), 45-51.

Taha, N. A., Hamden, S., Bayoumi, Y. A., Elsakhawy, T., El-Ramady, H., & Solberg, S. Ø. (2023). Nanofungicides with selenium and silicon can boost the growth and yield of common

bean (*Phaseolus vulgaris* L.) and control Alternaria leaf spot disease. *Microorganisms*, *11*(3), 728. DOI: 10.3390/microorganisms11030728.

Wang, L., Tu, H., Hou, H., Zhou, Z., Yuan, H., Luo, C., & Gu, Q. (2022). Occurrence and detection of carbendazim resistance in *Botryosphaeria dothidea* from apple orchards in China. *Plant Disease*, *106*(1), 207-214. DOI: 10.1094/PDIS-06-20-1204-RE

Wang, J., Zhu, L., & Zhang, C. Q. (2025). Resistance development to procymidone and boscalid in *Alternaria alternata* causing black spot disease on *Fritillaria thunbergii*. *Plant Disease*, *109*(9), 1959-1965. DOI: 10.1094/PDIS-12-24-2638-RE

Xu, Q., Zhang, K., Fu, Y., Ma, H., & Zhu, F. (2020). Toxic action and baseline sensitivity of boscalid against *Penicillium digitatum*. *Crop Protection*, *137*, 105272. DOI: 10.1016/j.cropro.2020.105272

Yin, Y., Miao, J., Shao, W., Liu, X., Zhao, Y., & Ma, Z. (2023). Fungicide resistance: Progress in understanding mechanism, monitoring, and management. *Phytopathology®*, *113*(4), 707-718. DOI: 10.1094/PHYTO-10-22-0370-KD

Zhang, C. Q., Yuan, S. K., Sun, H. Y., Qi, Z. Q., Zhou, M. G., & Zhu, G. N. (2007). Sensitivity of *Botrytis cinerea* from vegetable greenhouses to boscalid. *Plant Pathology*, *56*(4), 646-653. DOI: 10.1111/j.1365-3059.2007.01611.x

A DIFFERENT EXTRACTION PROCEDURE IN OLIVE OIL PRODUCTION

ZEYTİNYAĞI ELDESİNDE FARKLI BİR SIKIM PROSEDÜRÜ

Dr. CANSU DÖLEK

Çukurova Üniversitesi Kozan Meslek Yüksekokulu, Bahçe Tarımı Programı, Kozan, Adana, Türkiye

ORCID ID: 0000-0001-7628-0676,

Prof. Dr. MÜCAHİT TAHA ÖZKAYA

Ankara Üniversitesi Ziraat Fakültesi, Bahçe Bitkileri Bölümü,

ORCİD: :0000-0002-6571-5985

ÖZET

Ülkemiz zeytin ve zeytinyağı açısından büyük önem taşımaktadır. Zeytinyağının en önemli bileşenleri fenollerdir. Zeytinyağının elde edilme yöntemlerine göre miktarları değişiklik göstermektedir. Türk Gıda Kodeksi Zeytinyağı Ve Pirina Yağı Tebliği'ne göre zeytinyağları asitlik derecesi açısından doğrudan tüketime uygun veya tüketilemez şekilde 2 grupta bulunur. Bu durumu etkileyen en önemli faktörler çeşit, ekoloji, bakım koşulları ve hasat zamanını yanı sıra işleme teknolojisidir. Zeytinyağında kalitenin belirlenmesi ile ilgili çalışmalarda genellikle soxhelet yöntemi kullanılmaktadır. Fakat bu yöntem sırasında yüksek sıcaklık ve sürtünme etkisi nedeniyle fenolik bileşenler miktarının tam net tespit edilemediği düşünülmektedir. Zeytinyağı miktarının az olduğu çalışmalarda Abencor sistemi kullanılarak yapılan araştırmalarda, yağ kalitesi daha doğru bir şekilde tespit edilebilmektedir. Fakat bu makinenin yüksek fiyatlarda olması nedeniyle bulunması zordur. Aynı zamanda literatürde laboratuvar koşullarında zeytinyağı çıkarmak için farklı çalışmalarda bildirilmiştir. Bu çalışmada zeytinyağı ekstraksiyon yöntemleri üzerinde durulmuş, sanayi tipi ve laboratuvar koşullarında ekstraksiyon olmak üzere iki ana başlıkta incelenmiştir. Bunun yanı sıra çalışmada laboratuvarda küçük miktarlarda zeytin örnekleri için geliştirdiğimiz yağ çıkarma metodu literatüre kazandırılmak istenmiştir. Bu şekilde daha kısa sürede ve büyük makinelere ihtiyaç duymadan araştırma çalışmalarında kullanılabilecek küçük ölçekli bir metot hazırlanmıştır. Geliştirilen bu metodun akademik çalışmalara kolaylık sağlayacağı düşünülmektedir.

Anahtar Kelimeler: Abenkör, Ekstraksiyon, Soğuk Sıkım, Soxhelet, Zeytinyağı.

ABSTRACT

Our country holds significant importance in terms of olive and olive oil production. The most important components of olive oil are phenolic compounds. The quantity of these compounds varies depending on the method of olive oil extraction. According to the Turkish Food Codex Communiqué on Olive Oil and Pomace Oil, olive oils are classified into two groups in terms of acidity level: those suitable for direct consumption and those not suitable. The most critical

factors affecting this classification include variety, ecology, cultivation conditions, harvest time, and processing technology.

In studies related to the determination of olive oil quality, the Soxhlet method is generally employed. However, due to the high temperature and friction effects involved in this method, it is believed that the exact amount of phenolic compounds cannot be accurately determined. In studies involving small amounts of olive oil, the Abencor system allows for more accurate determination of oil quality. Nevertheless, due to the high cost of this equipment, it is not readily accessible. Additionally, various other laboratory-based olive oil extraction methods have been reported in the literature.

This study focuses on olive oil extraction methods and examines them under two main headings: industrial-scale and laboratory-scale extractions. Moreover, it introduces a new oil extraction method developed for small quantities of olive samples in laboratory settings. In this way, a small-scale method that does not require large machinery and can be used in research studies within a shorter time frame has been developed. It is believed that this method will facilitate academic research.

Keywords: Abencor, Cold Press, Extraction, Olive Oil, Soxhlet.

GİRİŞ

Zeytin ağacının yayılış alanı, hem kuzey hem de güney yarım kürelerde 30° ve 45° enlemleri arasında bulunmaktadır. Zeytin, kurak ve sıcak ekolojilere adapte olmuş Akdeniz iklimi bitkisidir (Pansiot and Rebour,1964). Ülkemiz zeytin ve zeytinyağı açısından büyük önem taşımaktadır. Zeytinyağının en önemli bileşenleri fenollerdir. Zeytinyağının elde edilme yöntemlerine göre miktarları değişiklik göstermektedir. Rodis vd. (2002) mevcut meyve fenollerinin yalnızca %1-2'sinin zeytinyağına aktarıldığını, geri kalanının (%98) atıklarla birlikte kaybolduğunu bildirmiştir. Zeytin fenolleri, antioksidan, antimikrobiyal, antikanser ve diğerleri gibi çeşitli biyoaktiviteleri nedeniyle son birkaç on yılda artan bir ilgi görmüştür ve bunları en değerli ve umut verici diyet bileşiklerinden biri olarak belirlemiştir (Obied vd. 2007; Obied vd. 2005; Jerman Klen vd. 2015).

Natürel zeytinyağları, zeytin ağacı meyvesinden, doğal özelliklerini değiştirmeyecek bir sıcaklıkta sadece mekanik veya fiziksel işlemler uygulanarak elde edilen, berrak, yeşilden sarıya değişebilen renkte, kendine özgü tat ve kokuda olan doğal halinde gıda olarak tüketilebilen yağlardır. Natürel zeytinyağları diğer nebati yağlardan farklıdır. Bu farklılığa neden olan en temel iki özellikten ilki; zeytin meyvesinin doğasından kaynaklanmaktadır. İkincisi ise eğer hammadde, yani zeytin, iyi kalitede ise tamamen mekanik yollarla elde edilen yağın anında yenilebilir nitelikte olmasıdır (Göğüş ve Yıldırım. 2009).

Zeytin meyvelerinin soğuk preslemeyle ekstraksiyonuyla elde edilen sızma zeytinyağı (EVOO), önemli bir bileşendir. EVOO'nun kimyasal bileşimi karmaşıktır ve aralarında fenolik bileşiklerin ve polifenollerin bulunduğu heterojen bir bileşik karışımı içerir. Polifenoller, fenolik asitler, fenolik alkoller, sekoiridoidler, lignanlar ve flavonoidler gibi farklı maddeleri içerir. Fenolik bileşikler, mükemmel bir antioksidan kaynağı oldukları için incelenmiştir ve özellikleri kronik hastalıkların önlenmesinde insan sağlığına faydalar sağlar (Tripoli vd. 2005).

Zeytinyağı sıkım prosedürü, yıkama ve yabancı maddelerden ayırma, kırma, yoğurma (malaksasyon), katı-sıvı faz ayrımı (dekantör) ve sıvı-sıvı faz ayrımı (seperasyon) kısımlarından oluşmaktadır. Bu aşamalarda zeytin hamuru ve yağın kalış süresi ve sıcaklık derecesi yağ miktarı ve içerik bileşimi açısından önem arz etmektedir. Zeytinyağının oluşumu sırasında etkili olan faktörler ve sistemler aşağıda açıklanmıştır.

Sızma zeytinyağı kalitesi zeytin çeşidi, iklim özellikleri, bitki besleme, hasat, depolama ve işleme teknikleri gibi farklı faktörlere bağlıdır. Pouyafard vd. (2016) zeytin ağaçlarında su stresinde bazı fizyolojik ve morfolojik değişimler olduğunu bildirmiştir. Bu durum aynı şekilde zeytinyağı kalitesini de etkilemektedir. Zeytin kırma, sızma zeytinyağının organoleptik ve besinsel nitelikleri üzerinde önemli bir etkiye sahiptir. Metalik kırıcılar kullanıldığında, yağlar şiddetli etki nedeniyle daha yüksek fenolik bileşik içeriğine sahiptir ve daha acı ve keskindir. Zeytin ezmesi yoğurma işlemi yağ verimini ve ayrıca yağın antioksidan içeriğini etkiler. Uzun süreli yoğurma ile yağ verimi genellikle artarken yağların fenol içeriği azalır. Zeytin ezmesinin katı ve sıvı fazlarından yağın ayrılması basınç, süzme veya santrifüjleme sistemleri kullanılarak gerçekleştirilir (Di Giovacchino vd. 2002a).

Hamur yoğrulurken makinelerin dışına su verilerek zeytin hamuru ısıtılır. Verilen suyun sıcaklığı 27 ^{0}C'den düşükse soğuk sıkım zeytinyağı, 27-50 ^{0}C arasında ise sıcak sıkım zeytinyağı olarak değerlendirilir. Sıcak su kullanılarak katı hamurdan daha fazla yağın ayrılması ve yağ oranını arttırmak hedeflenmektedir (Anonim, 2024a). Üretim sırasında zeytinyağının kalitesine en fazla etki eden şartlar malaksiyon işlemi sırasında oluşur. Malaksiyon kırılıp parçalanan zeytinin hamur haline getirilerek yoğurulması işlemidir. Bu işlem sırasında yağın daha fazla çıkması için zeytin hamuruna verilen su 40-45 °C'lere kadar çıkabilir. Kalua vd. (2006), hamur ısısının belli bir sıcaklığın üzerine çıkmasının elde edilen zeytinyağı kalitesini bozduğunu belirtmiştir (Erinç vd. 2018; Kızılaslan ve Birsin, 2022). Salas ve Sánchez (1999) geleneksel basınç yağ çıkarma prosedüründe, ikinci adım olan malaksasyon genellikle 30 °C'de 30 dakika boyunca gerçekleştirildiğini, ancak bu parametrelerin hamurun özelliklerine bağlı olarak değişebildiğini belirtmişlerdir. Diğer taraftan, günümüzde daha yaygın olan sürekli santrifüjleme yağ çıkarma prosedürü daha uzun malaksasyon sürelerini içerir. Sıcaklık bu derecenin üstüne çıktığında ise enzimlerin de etkisiyle zeytinyağında kusurlar oluşmaya başlamaktadır.

Gıdalardaki yağ miktarı, süt ve süt ürünlerinde Gerber yöntemiyle, bunun dışında kalan gıdalarda ise sokselet (soxhelet) yöntemiyle saptanmaktadır. Sokselet (soxhelet) ekstraksiyon cihazı kullanılarak uygun bir çözücü ile örnekteki yağın ekstrakte edilmesi ilkesine dayanır. Bu yöntemde çözücü olarak normal pentan veya hekzan kullanılır. Bu şekilde örnekten elde edilen yağ miktarı, yöntemde belirtilen şartlarda ekstrakte edilen maddenin tümüdür ve % olarak ifade edilir. Analiz edilecek örneğin nem oranının %10'un altında olması için örnek bir kurutma kabına konarak 80 ^{0}C'den fazla olmayan sıcaklıkta etüvde kurutulur. Yağ ekstraksiyonu, öğütmeden sonra 30 dakika içinde tamamlanmalıdır. Daha önce etüvde kurutulmuş ve desikatörde soğutulmuş olan ve içinde iki tane cam boncuk bulunan balon 1 mg duyarlılıkta tartılarak darası alınır. Örnek öğütüldükten sonra yaklaşık 5-10 g ± 0.5 mg duyarlılıkta tartılır. Tartılan numune, çözücü ile ıslatılmış küçük bir parça pamuk tampon kullanılarak kartuşa konur. Kartuş ekstraktöre yerleştirilir. Balona yeterli miktarda (yaklaşık 150 ml-1.5 sifon hacmi) çözücü ilave edilir. Balon, ekstraktör ve soğutucu birbirine bağlanır. Su banyosu veya ısıtıcılı tabla üzerine yerleştirilir. 6-8 saatlik ekstraksiyon uygulanır. Balonun içerisindeki çözücünün büyük bir kısmı damıtılarak geri alınır. Bu işlem sırasında yağ balonu içerisinde toplanan yağın yanmamasına dikkat edilmelidir (Anonim, 2025b).

Sokseletin (SE'nin), diğer geleneksel katı numune hazırlama teknikleriyle karşılaştırıldığında en ciddi dezavantajları şunlardır: (1) ekstraksiyon için gereken uzun süre ve sadece atılması pahalı olmakla kalmayıp aynı zamanda ek çevre sorunlarına da neden olabilen büyük miktarda ekstraktant atığı; (2) geleneksel Soxhlet ekstraktörü, adımı hızlandıracak olan çalkalamayı sağlayamaz; (3) kullanılan büyük miktarda çözücü nedeniyle, ekstraksiyondan sonra bir buharlaştırma/konsantrasyon adımı zorunludur (López-Bascón and De Castro, 2020).

Yeni numune hazırlama tekniklerini geliştirmenin ve mevcut numune hazırlama tekniklerini iyileştirmenin temel hedefleri şunlardır: (1) insan müdahalesini önlemek veya en aza indirmek

için otomasyon; (2) mümkün olan en kısa sürede çok sayıda numunenin işlenmesini sağlamak için hızlandırma; ve (3) çözücü ortadan kaldırma veya mümkün değilse daha az toksik çözücülerin azaltılmış hacimlerinin kullanılmasıdır (de la Guardia and Garrigues, 2012; Rı´os vd. 2009; López-Bascón and De Castro, 2020).

"Abenkör" zeytinyağı üretiminde kalite ve verim değerlendirmesi için kullanılan küçük ölçekli bir ekstraksiyon sistemi olarak tanımlanabilir ve özellikle araştırma ve kalite kontrol çalışmalarında tercih edilmektedir. Abenkör sistemi, zeytinlerin laboratuvar ortamında kontrollü koşullarda işlenmesini sağlar. Sistem, zeytinlerin ezilmesi, hamurun karıştırılması ve santrifüj yoluyla yağın ayrıştırılması aşamalarını içermektedir. Bu sayede, farklı zeytin çeşitlerinin, hasat zamanlarının veya işleme yöntemlerinin zeytinyağı kalitesi ve verimi üzerindeki etkileri detaylı olarak incelenebilir (Uyanık and Gümüşkesen, 2024).

Zeytin meyvesi nemi, EVOO'nun fenolik içeriğini olumsuz yönde etkiliyor gibi görünmektedir; yağa fenolik transfer oranı daha düşük olan bu çeşitler, zeytin meyvelerinde yüksek oranda nem sunmuştur (Talhaoui vd. 2016). %50'den fazla nem içeriğinin, yağ çıkarma için "zor" zeytin ezmesine neden olduğu düşünülmüştür (Di Giovacchino, 1991; Cecchi vd. 2019). Fenolik bileşikler esas olarak zeytin ezmesinin su ve yağ fazları arasında dağılmıştır. Fenolik bileşiklerin su fazına olan daha büyük afinitesi, zeytin meyvelerinde bulunan fenollerin yalnızca %0,05-1'inin yağa aktarıldığı anlamına gelir (Cecchi vd. 2018). EVOO'nun fenolik bileşik içeriğini artırmak için yağ çıkarma sırasında su temininin sınırlandırılması önerilebilir (Cecchi vd. 2019).

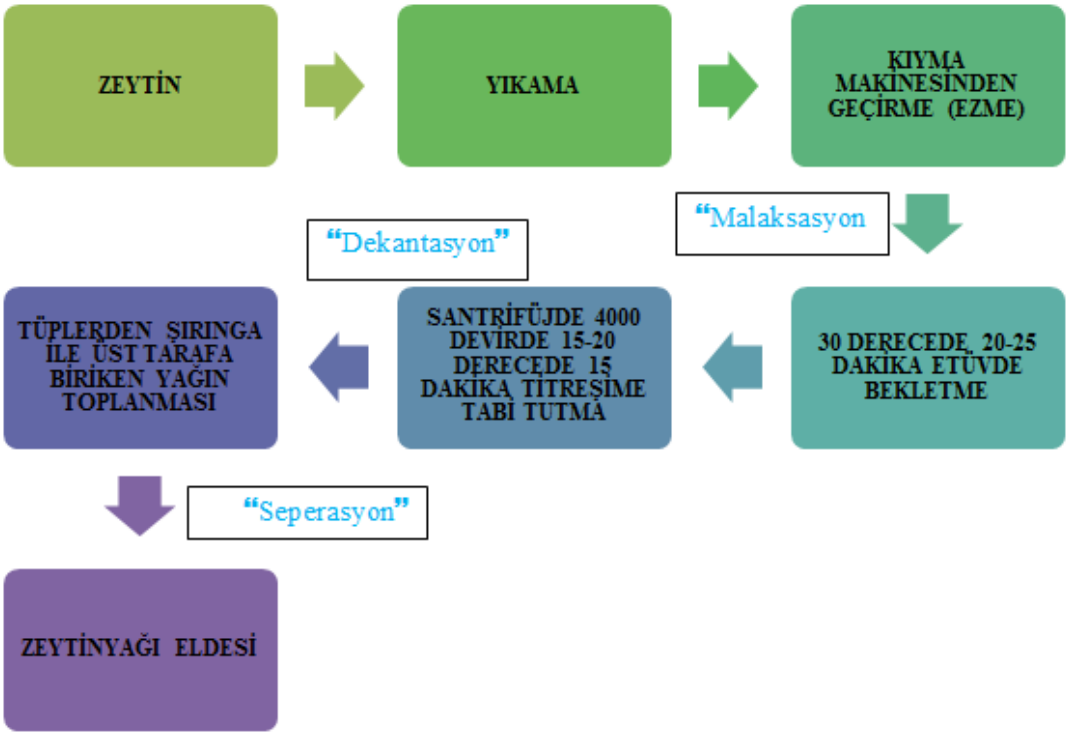
MATERYAL VE YÖNTEM

Zeytinyağının soğuk sıkım olarak elde edilmesi için yeni bir ekstrasyon tekniği geliştirilmiştir. Bu sayede küçük ölçekli çalışmalarda zeytinyağı sıkımı için yeni bir bakış açısı sunulmuştur. Rengi dönmeye başlayan zeytinler toplandıktan sonra aynı gün laboratuvara getirilir. Buzdolabında +4 ^{0}C de 2-3 gün kadar bekletilebilir. Fakat gün içerisinde tamamlanacak kadar miktarla ilerlenirse daha fazla yağ elde etmek için uygun olacaktır. Zeytinler yabancı maddelerden ayrıştırmak ve tozunu gidermek için yıkanır. Suyunun tamamen akıtılması sağlanır. Daha sonra meyveler kıyma makinesinden geçirilir. Meyve miktarının fazla olması ve çekirdeklerin küçük olması kıyma makinesinden geçişi kolaylaştırmaktadır. Çekirdeklerin makineyi tıkamamasına dikkat edilmelidir. Zeytinler fazla bekletilmeden kıyma makinesinden geçirilerek behere alınır. Ardından ağzı kapalı bir şekilde 30 ^{0}C de etüve konur. Elde edilen hamur 20-25 dakika etüvde bekletilir. Bu aşamaya kadar kısım fabrikadaki malaksör aşamasını içermektedir. Daha sonra 16'lık tüplere koyularak santrifüj için hazırlanır. Hamur tüpün yarısı kadar doldurulur. Santrifüj içerisine karşılıklı olarak yerleştirilir. 4000 devirde 15-20 ^{0}C de 15 dakika boyunca titreşime tabi tutularak yağın üst tarafta birikmesi sağlanır. Bu aşama ise katı sıvı faz ayırma aşaması olan dekantör görevi görmektedir. Sonrasında şırınga ile üst tarafa biriken yağ bir kaba tüpe doldurulur. En son aşama separatör aşamasıdır ve yağ geri kalan maddelerden ayrılarak saf hale getirilir (Şekil 1, 2). Analiz edilmek üzere +4 ^{0}C de buzdolabında saklanır. Eğer daha uzun süre bekletilecekse -22 ^{0}C de bekletilmelidir. Sıcak sıkım ile düşük değerlere sahip olacak fenolik bileşenler bu yöntemle birlikte daha doğru sonuçlar verecek ve yağa daha iyi bir şekilde geçebilecektir.

Şekil 1. Zeytinyağı eldesinde yeni yöntemin ilerleme aşamaları

BULGULAR VE TARTIŞMA

Çalışmada geliştirilen metot ile birlikte laboratuvar koşulllarında kısa sürede ve kolay bir şekilde yağ çıkarma imkanı sağlanmıştır. Zeytinyağı sıkım prosedürü aşağıdaki şema ile gösterilmiştir. Bu sayede herhangi bir kimyasal veya yüksek sıcaklık uygulaması olmadan işleme gerçekleşmektedir. Fakat çıkarılan yağ miktarı diğer yöntemlere göre daha az olmaktadır.



Şekil 2. Zeytinyağı eldesinde prosedürün akış şeması

Bir zeytinyağı değirmeni basınç sistemiyle donatıldığında, zeytin kırma genellikle 20-30 dakika boyunca granit değirmen taşları (2-6 taşlı) tarafından gerçekleştirilir. Elde edilen zeytin ezmesi daha sonra bir hidrolik presle sıkılır. Bu şekilde iyi yağ çıkarma verimleri elde edilir (Di Giovacchino and Solinas, 1987). Bir zeytinyağı değirmeni santrifüjleme sistemiyle donatıldığında, zeytin kırma genellikle mobil veya sabit çekiçler, dişli diskler, koniler veya silindirler gibi metalik kırıcılar tarafından gerçekleştirilir (Munoz Aranda and Alba Mendoza, 1980). Zeytin ezme işleminden sonra elde edilen zeytin ezmesi, sonraki yağ ayırma adımı için iyi bir şekilde hazırlanması ve daha iyi bir ekstraksiyon verimi elde edilmesi için malakslanmalıdır. Basınç sistemiyle çalışan bir zeytinyağı değirmeninde, zeytin ezmesi için malaksasyon süresi 10-20 dakikadır ve sıcaklık 20-25 °C'den yüksek değildir. Genel olarak, zeytin ezmesi malaksasyonunun süresi ve sıcaklığı arttıkça yağ oranında bir artış olduğu bildirilmiştir (Di Giovacchino, 1991). Yoğurma süresi ayrıca, laboratuvar ölçeğinde bitkilerle yapılan bazı araştırmalarda (Montedoro vd. 1994; Servili vd., 1992; Lercker vd. 1999; Angerosa vd. 2001; Angerosa vd. 1998) veya endüstriyel zeytinyağı fabrikalarında Di Giovacchino vd. (2002a)' nin bildirildiği gibi, yağların uçucu maddelerinin bileşimini de etkilemektedir.

Yağın toplam fenol içeriği, yalnızca malaksasyon sırasında zeytin ezmesinin sıcaklığı arttığında değişebilir. Küçük laboratuvar tesislerinde gerçekleştirilen bazı araştırmalarda, malaksasyon adımı sırasında zeytin ezmesinin sıcaklığındaki artışın, yağın toplam fenol içeriğinde bir azalmaya yol açtığı belirtilmiştir [Montedoro vd. 1994; Servili vd. 1992; Angerosa vd. 2001;

Servili vd. 1994). Bu durumda, laboratuvar ölçeğinde gerçekleştirilen testlerden elde edilen sonuçların bazen endüstriyel bir zeytinyağı fabrikasında elde edilecek sonuçları tahmin etmede yararlı olmadığı açıktır (Di Giovacchino vd. 2002b). Geliştirilen yöntem ile ezme sonucunda elde edilen hamur yumuşak dokulu olmakta, çelik bıçaklar sayesinde büyük parçalar kalmamaktadır. Etüvde ise uygun sıcaklık derecesi sağlandığından yağların açığa çıkması kolaylaşmakta ve hamura su eklemeye gerek kalmamaktadır. Nitekim bu durum, diğer yöntemlerde ortaya çıkan problemi engellemektedir. Eğer kullanılan meyvelerde su oranı az olursa odunsuluğu önlemek amacıyla 20-25 ^{0}C civarında bir miktar su eklenmesi mümkün olabilmektedir.

Çekirdekleri kırmak için gereken güç, yüksek enerji dağılımı ve kütlenin önemli ölçüde ısınması ile şoklar, vurmalı çalkantılar, ezme ve şiddetli darbeler üretir (Romaniello vd. 2017; Squeo vd. 2017). Bu durumda meyve kuru ise ve içeri su da verilmiyorsa fazla sürtünme ve ısı artışına bağlı olarak yağda odunsu bir his tespit edilebilir. Bu etkiler, EVOO'nun son miktarını ve fenolik ve uçucu profillerini etkileyen endojen enzimatik aktivitelerde önemli bir rol oynar (Servili and Montedoro, 2002; Servili vd. 2011). Caponio vd. (2003), çekiçli değirmenin taş değirmenlere göre bitki dokularından daha fazla miktarda fenol çıkarmayı mümkün kıldığını ve sonuç olarak çekiçli kırıcı ile üretilen yağın taş değirmenlerle elde edilenden daha acı ve daha yüksek antioksidan kapasiteye sahip olduğunu bulmuşlardır. Zeytin çekirdeği, tüm çekirdekte yüksek düzeyde peroksidaz (POX) aktivitesi içerir (Luaces vd. 2007; Servili vd. 2007), bu da fenollerin oksidatif reaksiyonlarını etkiler ve VOO fenolik içeriğini belirlemede önemli bir rol oynamaktadır (Garcia-Rodriguez vd. 2015). Tohum dokularının hafif bir şekilde bozulması veya bir çekirdek ayırma makinesinin kullanımı nedeniyle POX'un sınırlı aktivitesi, mekanik ekstraksiyon işlemi sırasında VOO'ların fenolik bileşiklerinin iyileştirilmesine ilişkin sonuçları doğrulamaktadır (Garcia-Rodriguez vd. 2015; Tamborrino vd. 2020; Amirante vd. 2006; Angerosa and Di Giacinto, 1995; Manganiello vd. 2021, Taticchi vd. 2014; Tamborrino vd. 2022).

Zeytinyağı üretim aşamalarında kullanılan suyun sıcaklığı soğuk sıkım ve sıcak sıkım gibi iki kavramı ortaya çıkarmıştır. Üretim tekniği açısından zeytinin yağa dönüşene kadar geçirdiği evreler aynı olmakla birlikte farklılığı yaratan sadece suyun derecesidir. Bu durum soğuk sıkımda zeytinyağı kalitesinin yüksek olmasını sağlar. Bunun yanı sıra en önemli faktörlerden diğeri ise meyvelerin erken hasat edilmiş ve en kısa sürede tesise ulaşmış olmasıdır. Sıcak veya soğuk su kullanımı yoğurma aşamasında hamur ve yağın birbirinden ayrılması için kullanılmaktadır.

Nebioğlu (2020) sızma zeytinyağının duyusal özellikleri ve biofenol miktarının depolama koşullarına ve süresine göre değişiklik gösterdiğini belirtmiştir. Yaptığı çalışmada Gemlik çeşidinde biofenol miktarlarında değişen malaksasyon sıcaklık ve sürelerinde genel olarak düşüş gözlenmekle birlikte sıcaklığın 50°C'ye çıkması ile bir miktar yükseldiği gözlemlenmiştir. Ancak en yüksek biofenol miktarı 30°C ve 30 dakikalık (G1) malaksasyon sonucu elde edilen üründe tespit edilmiştir (227 kg/mg). Garcıa-Ayuso and De Castro, (1999) çalışmalarında soxhelet yöntemini kullanmış ve ortaya çıkabilecek olumsuz durumlara karşı öneri getirmişlerdir. Sızdırma işleminin hızlandırılması için ekstraksiyon haznesinde odaklanmış mikrodalgalarla desteklenen geleneksel bir Soxhlet ekstraktöründen oluşan bir prototip, tohumlardan (zeytin) yenilebilir yağın çıkarılmasına uygulanarak kontrol edilmiştir. Soxhlet ekstraksiyonunun tipik özelliği olan, numunenin taze çözücüyle sürekli teması, ekstraksiyon dengesini sürekli olarak bozar ve böylece bu yaklaşım, ekstraksiyon adımı boyunca numuneyle önceden belirlenmiş bir hacimde ekstraktantın temas halinde tutulduğu kapalı yöntemlerden daha etkili hale gelmektedir.

Zeytinyağı miktarının az olduğu çalışmalarda Abencor sistemi kullanılarak yapılan araştırmalarda, yağ kalitesi daha doğru bir şekilde tespit edilebilmektedir. Otağ ve Gümüşkesen

(2023) Ayvalık ve Memecik zeytin çeşitlerinden Abencor yöntemi kullanarak zeytinyağı elde etmişlerdir. Bu sistemle yapılan çalışmada, zeytinyağı üretiminde verim artırıcı maddelerin (örneğin doğal mikronize talk ve enzimler) kullanımının yağ verimi ve kalitesi üzerindeki etkilerini incelemiştir. Sonuçlar, %1 oranında doğal mikronize talk kullanımının yağ verimini artırdığı ve zeytinyağı kalitesinde olumsuz değişiklik yaratmadığını göstermiştir. Başka bir çalışmada Uyanık ve Gümüşkesen (2024) Urla/İzmir bölgesinde organik ve geleneksel yöntemlerle yetiştirilen Erkence çeşidi zeytinlerden, Abencor sistemi kullanılarak elde edilen zeytinyağlarının kimyasal ve duyusal özelliklerini incelemişlerdir. Bu çalışma, zeytinin olgunlaşma düzeyi ve yetiştirme yöntemlerinin yağ kalitesi üzerindeki etkilerin belirlenmesinde yağ çıkarma yönteminin önemini de ortaya koymuştur.

Yapılan bir çalışmada Cecchi vd. (2019) laboratuvar ölçeğinde, zeytin ezmesi neminin hem yağ çıkarma verimi hem de fenolik içerik ve çıkarılabilir zeytinyağından elde edilen profil üzerindeki etkisini, dondurularak kurutulmuş zeytin ezmesinin geniş bir nem aralığında kademeli olarak seyreltilmesi yoluyla fiziksel ve biyokimyasal olarak incelemiştir. Frantoio ve Leccio del Corno çeşitlerinin zeytin meyveleri hasattan hemen sonra dondurularak kurutulmuş ve ardından öğütülmüştür (Cecchi vd. 2015). Deneyler, ekstrakte edilebilir yağda yağ çıkarma veriminin ve fenolik transfer veriminin arttığını ve tam zeytin meyvelerinin öğütülmesi sırasında zeytin ezmesi nem değerlerinden daha düşük zeytin ezmesi nem değerlerinde maksimuma ulaştığını göstermiştir. Veriler ayrıca zeytin ezmesi neminin, çıkarılan yağların fenolik profilini etkileyen enzimatik olaylarda önemli bir rol oynadığını ve meyvelerde bulunmayan veya diğer moleküllere bağlı olan lignanların, enzimlerin ve suyun eş varlığı sayesinde yağ çıkarma sırasında serbest bırakıldığı veya biyosentezlendiği hipotezini doğrulamaktadır (Cecchi vd. 2019).

Yapılan başka çalışmada ise Jerman Klen vd. (Jerman Klen vd. 2015) zeytinyağı işleme sırasında zeytin meyvesi fenollerinin niceliksel davranışını kapsamlı bir şekilde incelemişlerdir. Toplamda, ultra yüksek basınçlı sıvı kromatografisi-diyot dizisi algılama analizi kullanan üç fazlı bir ekstraksiyon hattından 6 zeytin matrisinde 69 fenol niceliksel olarak belirlenmiştir. Çok sayıda meyve, temsili başlangıç meyve materyali olarak rastgele seçilmiş, tartılmış ve dondurularak kurutulmadan önce sıvı nitrojenle dondurulmuştur. Çekirdekleri çıkarılan meyveler, çekirdekler, macun ve posa sıvı nitrojenle dondurularak kurutulmuş, homojenleştirilmiş ve analiz edilene kadar -25 °C'de saklanmıştır (Jerman vd. 2010; Jerman Klen and Mozetič Vodopivec, 2011; Jerman Klen and Mozetič Vodopivec, 2012). Dondurularak kurutulmuş örneklerin kuru madde ölçümleri gravimetrik olarak gerçekleştirilmiş ve fenol transferi/bölüşüm hesaplamalarının temelini oluşturmuştur. Kabuk ve posa birlikte toplam meyve fenollerinin %95'ini sınırlarken, çekirdek yalnızca %5'ini sınırlanmıştır (Lesage-Meessen vd. 2001).

Sıvı-sıvı ekstraksiyonunda (LLE), iki karışmayan çözücünün karışımı, analitin iki faz arasında dağıtılması yoluyla ayırma işlemini yönlendirmek için seçilir. Zeytinyağının polifenol ekstraksiyonunun özel durumunda, su ve n-hekzan içinde seyreltilmiş metanol veya etanol gibi çözücüler önerilir (Bonoli vd. 2003; International Olive Council, 2009; Pirisi vd. 2000). Ancak, bu teknik pahalı ve tehlikeli organik çözücüler ve analiz başına uzun bir zaman gerektirir ve bu da fenolik bileşiklerin stabilitesini ve nihai toplam konsantrasyonlarını etkileyebilir. Chávez Ramos vd. (2020) son yıllarda, yeni ekstraksiyon yöntemlerinin araştırılmasının giderek daha önemli hale geldiğini ve sıvı faz mikroekstraksiyon (LPME) ve mikroteknolojiye yönelme gerçekleştiğini bildirmiştir (Monasterio vd. 2013; Spietelun vd. 2014).

Zeytinyağında kalitenin belirlenmesi ile ilgili çalışmalarda genellikle soxhelet yöntemi kullanılmaktadır. Fakat bu yöntem sırasında yüksek sıcaklık ve sürtünme etkisi nedeniyle fenolik bileşenler miktarının tam net tespit edilemediği düşünülmektedir. Aynı zamanda bu yöntemle kimyasal kullanımı da olduğundan yağın içerisindeki bileşenleri ve antioksidan

kapasiteyi değiştirebilmektedir. Zeytinyağı fabrikasında soğuk sıkım zeytinyağı eldesi ile sağlık bileşenleri yüksek bir yağ elde etmek mümkündür. Sıcak sıkım tekniği ise zeytinyağında çabuk bozulma etkisi vermekte, yağ miktarı artarken, içeriğindeki bileşenler düşmektedir. Laboratuvar çalışmalarında gıda olarak tüketim olmayacağı için zeytinyağında bu durum yok sayılabilmektedir ve uygulamalar arasındaki farklılıklar değerlendirilmektedir. Bu değerlerde daha net sonuçlar ortaya koyabilmek ve bundan sonraki çalışmalar için karşılaştırmalı analiz yapılabilmesi için bu soğuk sıkım metodu geliştirilmiştir.

SONUÇ

Bu çalışmada farklı zeytinyağı çıkarımı yöntemleri açıklanmış ve yeni bir metot eklenerek, elde olan imkanlarla daha kolay bir şekilde zeytinyağı eldesi literatüre kazandırılmak istenmiştir. Soxhelet yönteminin kimyasal ve yüksek sıcaklık içermesinden dolayı zeytinyağının içerisindeki bileşimi tam olarak ortaya koyamama, soğuk sıkım yapan tesislerin ise büyük makineler ve yüksek oranda meyveye ihtiyaç duyulması problemi olduğu düşünülerek yeni geliştirilen bu yöntem az miktarda örneğin değerlendirilmesinde oldukça önemli görülmektedir. Çalışmada laboratuvarda küçük miktarlarda zeytin örnekleri için geliştirdiğimiz yağ çıkarma metodu literatüre kazandırılmak istenmiştir. Bu yöntemde zeytinyağı eldesinde kıyma makinesi, etüv ve santrifüj kullanılarak malaksör, dekantör ve seperatör basamakları tamamlanmaktadır. Bu şekilde daha kısa sürede ve büyük makinelere ihtiyaç duymadan araştırma çalışmalarında kullanılabilecek küçük ölçekli bir metot hazırlanmıştır. Geliştirilen bu metodun akademik çalışmalara kolaylık sağlayacağı düşünülmektedir.

KAYNAKLAR

Anonim, (2024a). Ekstraksiyon Yöntemiyle Yağ Tayini (Sokselet) https://diatek.com.tr/Makale_Yontem/Mikrobiyolojik-Analiz/Ekstraksiyon-Yontemiyle-Yag-Tayini-Sokselet_3432.htm, (Erişim Tarihi: 20.11.2024).

Anonim, (2025b). https://www.gaiaoliva.com.tr/zeytinyagi-secim-rehberi-sicak-ve-soguk-sikim-arasindaki-farklar-neler#:~:text=Suyun%20s%C4%B1cakl%C4%B1%C4%9F%C4%B1%2027%20derecenin%20alt%C4%B1nda,daha%20fazla%20ya%C4%9F%20elde%20etmektir, (Erişim Tarihi: 10.03.2024).

Amirante, P., Clodoveo, M. L., Dugo, G., Leone, A. & Tamborrino, A. (2006). Advance technology in virgin olive oil production from traditional and de-stoned pastes: Influence of the introduction of a heat exchanger on oil quality. *Food Chem*., 98, 797–805.

Angerosa, F. & Di Giacinto, L. (1995). Quality characteristics of virgin olive oil in relation to crushing method. Note II. Riv. Ital. *Sostanze Grasse*, 72, 1–4.

Angerosa, F. Mostallino, R. Basti, C. & Vito, R. (2001). Influence of malaxation temperature and time on the quality of virgin olive oils. *Food Chem*. 72, 19-28.

Angerosa, F., D'Alessandro, N., Basti, C. & Vito, R. (1998). Biogeneration of volatile compounds in virgin olive oil: their evolution in relation to malaxation time. *J. Agric. Food Chem*. 46, 2940-2944.

Bonoli, M., Montanucci, M., Toschi, T.G., & Lercker, G. (2003). Fast separation and determination of tyrosol, hydroxytyrosol and other phenolic compounds in extra-virgin olive oil by capillary zone electrophoresis with ultraviolet-diode array detection. *J Chromatogr* A 1011(1–2):163–172.https://doi.org/10.1016/S0021-9673(03)01100-2.

Caponio, F., Gomes, T., Summo, C. & Pasqualone, A. (2003). Influence of the type of olive-crusher used on the quality of extra virgin olive oils. *Eur. J. Lipid Sci. Technol*., 105, 201–206.

Cecchi, L., Breschi, C., Migliorini, M., Canuti, V., Fia, G., Mulinacci, N. & Zanoni, B. (2019). Moisture in rehydrated olive paste affects oil extraction yield and phenolic compound content and profile of extracted olive oil. *European Journal of Lipid Science and Technology*, 121(4), 1800449.

Cecchi, L., Migliorini, M., Cherubini, C., Innocenti, M. & Mulinacci, N. (2015). Whole lyophilized olives as sources of unexpectedly high amounts of secoiridoids: the case of three Tuscan cultivars. *Journal of Agricultural and Food Chemistry*, *63*(4), 1175-1185.

Cecchi, L., Migliorini, M., Zanoni, B., Breschi, C. & Mulinacci, N. (2018). An effective HPLC-based approach for the evaluation of the content of total phenolic compounds transferred from olives to virgin olive oil during the olive milling process. *Journal of the Science of Food and Agriculture*, *98*(10), 3636-3643.

Chávez Ramos, K., Olguín Contreras, L.F. & del Pilar Cañizares Macías, M. (2020). Lab-on-a-chip extraction of phenolic compounds from extra virgin olive oil. *Food Analytical Methods*, *13*, 21-34.

De la Guardia, M. & Garrigues, S. (2012). *Handbook of green analytical chemistry*. NY: John Wiley.

Di Giovacchino L. (1991). L'estrazione dell'olio con la centrifugazione diretta delle paste di olive. Nota I: influenza della gramolazione. *Riv. Ital. Sost.* Grasse 68, 314-420.

Di Giovacchino, L. & Solinas, M. (1987). Incidenza della frangitura delle olive e della gramolazione delle paste sui rendimenti di estrazione dell'olio con il sistema della pressione. *Ann. Ist. Sper. Elaiotecnica* X, 201-208.

Di Giovacchino, L., Costantini, N., Ferrante, M.L. & Serraiocco A. (2002a). Influence of malaxation time of olive paste on the technological results and qualitative characteristics of virgin olive oil obtained by a centrifugal decanter at water saving. *Grasas Aceites* (in press).

Di Giovacchino, L., Sestili, S., & Di Vincenzo, D. (2002b). Influence of olive processing on virgin olive oil quality. *European Journal of Lipid Science and Technology*, *104* (9-10), 587-601.

Erinç, H., Yorulmaz, A. & Tekin, A. (2018). Malaksiyon Sıcaklık ve Süresinin Zeytinyağının Bazı Özellikleri Üzerine Etkisi. *Gıda*, 43 (5): 826-834.

Garcıa-Ayuso, L.E. & De Castro, M.L. (1999). A multivariate study of the performance of a microwave-assisted Soxhlet extractor for olive seeds. *Analytica Chimica Acta*, *382*(3), 309-316.

Garcia-Rodriguez, R., Romero-Segura, C., Sanz, C. & Perez, A.G. (2015). Modulating oxidoreductase activity modifies the phenolic content of virgin olive oil. *Food Chem*., 171, 364–369.

Göğüş, F. & Yıldırım, N. (2009). *Zeytinyağı İşleme Sistemleri. Zeytinyağı*. Editörler: Göğüş, F., Özkaya, M.T. ve Ötleş, S. Eflatun Yayınevi. Bölüm 3. Sf: 59-94.

International Olive Council. (2009). Determinación de los biofenoles de los aceites de oliva mediante hplc.

Jerman Klen, T. & Mozetič Vodopivec, B. (2011). Ultrasonic extraction of phenols from olive mill wastewater: comparison with conventional methods. *J. Agric. Food Chem*., 59, 12725−12731.

Jerman Klen, T. & Mozetič Vodopivec, B. (2012). Optimisation of olive oil phenol extraction conditions using a high-power probe ultrasonication. *Food Chem*., 134, 2481−2488.

Jerman Klen, T., Golc Wondra, A., Vrhovšek, U., Sivilotti, P., & Vodopivec, B.M. (2015). Olive fruit phenols transfer, transformation, and partition trail during laboratory-scale olive oil processing. *Journal of Agricultural and Food Chemistry*, *63*(18), 4570-4579.

Jerman T., Trebše P. & Mozetič Vodopivec, B. (2010). Ultrasound-assisted solid liquid extraction (USLE) of olive fruit (*Olea europaea*) phenolic compounds. *Food Chem*., 123, 175−182.

Kalua, C.M., Bedgood, D.R., Bishop, A.G., & Prenzler, P.D. (2006). Changes In Volatile and Phenolic Compounds With Malaxation Time and Temperature During Virgin Olive Oil Production. *J Agr Food Chem*. 54(20): 7641-7651.

Kızılaslan & Birsin, (2022). Yağlık Zeytin İşleyen İşletmelerin Mevcut Özellikleri, Üretim ve Pazarlama Sorunları (Tr 22 Bölgesi Örneği). *Gaziosmanpaşa Bilimsel Araştırma Dergisi* 11 (2), 250-267.

Lercker, G. Frega, N. Bocci, F. & Mozzon, M. (1999). Volatile constituents and oxidative stability of virgin olive oils: influence of the kneading of olive paste. *Grasas Aceites* 50, 26-29.

Lesage-Meessen, L., Navarro, D., Maunier, S., Sigoillot, J.-C., Lorquin, J., Delattre, M., Simon, J.-L., Asther, M. & Labat, M. (2001). Simple phenoliccontent in olive oil residues as a function of extraction systems. *Food Chem*., 75, 501−507.

López-Bascón, M.A., & De Castro, M.L. (2020). Soxhlet extraction. In *Liquid-phase extraction* (pp. 327-354). Elsevier.

Luaces, P., Romero, C., Gutiérrez, F., Sanz, C. & Pérez, A.G. (2007). Contribution of olive seed to the phenolic profile and related quality parameters of virgin olive oil. *J. Sci. Food Agric*., 87, 2721–2727.

Manganiello, R., Pagano, M., Nucciarelli, D., Ciccoritti, R., Tomasone, R., Di Serio, M.G., Giansante, L., Del Re, P., Servili, M. & Veneziani, G. (2021). Effects of ultrasound technology on the qualitative properties of Italian extra virgin olive oil. *Foods*, 10, 2884.

Monasterio R.P, De Los Angeles Fernández M, & Silva M.F. (2013). Highthroughput determination of phenolic compounds in virgin olive oil using dispersive liquid-liquid microextraction- capillary zone electrophoresis. *Electrophoresis* 34(12):1836–1843.https://doi.org/10.1002/elps.201300117.

Montedoro, G.F., Servili, M. & Baldioli, M. (1994). Lo stato di dispersione colloidale delle paste di oliva e le implicazioni sulle caratteristiche compositive dell'olio. Atti del Convegno "Le centrifughe a due fasi nell'estrazione dell'olio di oliva: problematiche, prospettive qualitative e implicazioni della utilizzazione dei sottoprodotti". Ed. Accademia Nazionale dell'Olivo, Spoleto (Italy), pp.21-41.

Munoz Aranda, E. & Alba Mendoza, J. (1980). Informe de la Almazara Experimental del Instituto de la Grasa correspondiente a la campana. *Grasas Aceites* 3, 423-433.

Nebioğlu, M. (2020). Gemlik ve memecik çeşitlerinden zeytinyağı üretiminde kullanılan farklı malaksasyon parametrelerinin biofenol miktarı ve duyusal profili üzerine etkisi. *Gıda ve Yem Bilimi Teknolojisi Dergisi*, (24), 55-64.

Obied, H.K.; Allen, M.S., Bedgood, D.R., Prenzler, P.D., Robards, K. & Stockmann, R. (2005). Bioactivity and analysis of biophenols recovered from olive mill waste. *J. Agric. Food 435 Chem*., 53, 823−837.

Obied, H.K., Bedgood, D.R., Prenzier, P.D., & Robards, K. (2007). Chemical screening of olive biophenol extracts by hyphenated liquid chromatography. *Anal. Chim. Acta*, 603, 176−189.

Otağ, M., & Gümüşkesen, A. (2023). Zeytinyağı Üretiminde Verim Artırıcı Maddelerin Kullanımının Bazı Kalite Özellikleri Üzerine Etkileri. *Karadeniz Fen Bilimleri Dergisi*, *13*(3), 1227-1241.

Pansiot, F.P. & Rebour, N. (1964). (Çev. Aksu, S. ve Kantar, M.), *Zeytincilikte Gelişmeler*. Tarım ve Köyişleri Bakanlığı, Zeytincilik Araştırma Enstitüsü, Yayın No. 3, Bornova/ İzmir.

Pirisi, F.M., Cabras, P., Cao, C.F., Migliorini, M., & Muggelli, M. (2000) Phenolic compounds in virgin olive oil. 2. Reappraisal of the extraction, HPLC separation, and quantification procedures. *J Agric Food Chem* 48PDF:1191–1196.

Pouyafard, N., Akkuzu, E., & Kaya, Ü. (2016). Kıyı Ege Koşullarında Yetiştirilen Ayvalık Zeytin Fidanlarında Su Stresine Bağlı Bazı Fizyolojik ve Morfolojik Değişimlerin Belirlenmesi. *Tekirdağ Ziraat Fakültesi Dergisi*, 13(1), 88-98.

Rı´os, A., Escarpa, A. & Simonet, B. (2009). Miniaturization of analytical systems: Principles, designs and applications. NY: John Wiley.

Rodis, P.S., Karathanos, V.T. & Mantzavinou, A. (2002). Partitioning of olive oil antioxidants between oil and water phases. *J. Agric. Food Chem*., 50, 596−601.

Romaniello, R., Leone, A. & Tamborrino, A. (2017). Specification of a new de-stoner machine: Evaluation of machining effects on olive paste's rheology and olive oil yield and quality. *J. Sci. Food Agric*., 97, 115–121.

Salas, J.J., & Sánchez, J. (1999). The Decrease of Virgin Olive Oil Flavor Produced by High Malaxation Temperature is due to Inactivation of Hydroperoxide Lyase. *Journal of Agricultural and Food Chemistry*, 47(3), 809-812.

Servili, M., & Montedoro, G.F. (2002). Contribution of phenolic compounds to virgin olive oil quality. *Eur. J. Lipid Sci. Technol*., 104, 602–613.

Servili, M., Baldioli, M. & Montedoro G. (1994). Phenolic composition of virgin olive oil in relationship to some chemical and physical aspects of malaxation. *Acta Horticulturae*. Olive Growing II 356(1994) 331-336.

Servili, M., Baldioli, M. & Montedoro G.F. (1992). *I meccanismi che influenzano la concentrazione in polifenoli dell'olio vergine di oliva.* Proceedings of International Congress "Olive Oil Quality". Ed.Regione Toscana, Firenze (Italy), pp.375-376.

Servili, M., Esposto, S., Taticchi, A., Urbani, S., Veneziani, G., Di Maio, I., Sordini, B. & Selvaggini, R. (2011). *Improvements on olive oil extraction plants in relation to oil quality.* In Proceedings of the 4th International Conference on "Olive Culture and Biotechnology of Olive Tree Products", Chania, Greece, 31 October–4 November 2011.

Servili, M., Taticchi, A., Esposto, S., Urbani, S.; Selvaggini, R. & Montedoro, G. (2007). Effect of olive stoning on the volatile and phenolic composition of virgin olive oil. *J. Agric. Food Chem*., 55, 7028–7035.

Spietelun, A., Marcinkowski, Ł., De La Guardia, M., & Namieśnik, J. (2014). Green aspects, developments and perspectives of liquid phase microextraction techniques. Talanta 119:34–45.https://doi.org/10.1016/j.talanta.2013.10.050.

Squeo, G., Tamborrino, A., Pasqualone, A., Leone, A., Paradiso, V. M., Summo, C. & Caponio, F. (2017). Assessment of the Influence of the Decanter Set-up During Continuous Processing of Olives at Different Pigmentation Index. *Food Bioprocess Technol*. 10, 592–602.

Talhaoui, N., Gómez-Caravaca, A.M., León, L., De la Rosa, R., Fernández-Gutiérrez, A., & Segura-Carretero, A. (2016). From olive fruits to olive oil: phenolic compound transfer in six different olive cultivars grown under the same agronomical conditions. *International Journal of Molecular Sciences*, 17(3), 337.

Tamborrino, A., Perone, C., Veneziani, G., Berardi, A., Romaniello, R., Servili, M., & Leone, A. (2022). Experimental investigation of a new modular crusher machine developed for olive oil extraction plants. *Foods*, 11(19), 3035.

Tamborrino, A., Servili, M., Leone, A., Romaniello, R., Perone, C. & Veneziani, G. (2020). Partial de-stoning of olive paste to increase olive oil quality, yield, and sustainability of the olive oil extraction process. *Eur. J. Lipid Sci. Technol*., 122, 2000129.

Taticchi, A., Esposto, S. & Servili, M. (2014). *The basis of the sensory properties of virgin olive oil.* In Olive Oil Sensory Science; Monteleone, E., Langstaff, S., Eds.; Wiley-Blackwell: Hoboken, NJ, USA,; pp. 33–54.

Tripoli, E., Giammanco, M., Tabacchi, G., Di Majo, D., Giammanco, S., La Guardia, M., & La Guardia, M. (2005) The phenolic compounds of olive oil: structure, biological activity and beneficial effects on human health. *Nutr Res Rev* 18(1):98–112.https://doi.org/10.1079/NRR200495.

Uyanık, E.B., & Gümüşkesen, A. (2024). Erkence Zeytin Çeşidinden Elde Edilen Zeytinyağlarının Kimyasal ve Duyusal Özeliklerine Organik ve Geleneksel Yetiştirme Yöntemlerinin ve Olgunluk Düzeyinin Etkisinin İncelenmesi. *Türk Tarım ve Doğa Bilimleri Dergisi*, 11(1), 180-189.

A MULTI-TEMPORAL ANALYSIS OF THE CORRELATION BETWEEN NDVI AND NDMI IN REMOTE SENSING-BASED PRECISION AGRICULTURE

UZAKTAN ALGILAMA TABANLI HASSAS TARIMDA NDVI VE NDMI ARASINDAKİ KORELASYONUN ÇOK ZAMANLI ANALİZİ

Dr. Öğretim Üyesi Mesut ÇOŞLU

Burdur Mehmet Akif Ersoy Üniversitesi, Fen-Edebiyat Fakültesi, Hassas Tarım ve Tarımsal Robotlar Bölümü

Doç. Dr. İlker ÜNAL

Burdur Mehmet Akif Ersoy Üniversitesi, Fen-Edebiyat Fakültesi, Hassas Tarım ve Tarımsal Robotlar Bölümü

ÖZET

Uydu tabanlı uzaktan algılama, bitki ve toprak koşullarının izlenmesinde sürekli, nesnel ve geniş alanları kapsayan veri sağlaması nedeniyle hassas tarım uygulamalarında temel bir araç olarak kullanılmaktadır. Bu çalışmada, tarım alanlarındaki bitki örtüsü dinamikleri ile nem içeriği arasındaki ilişkinin çok zamanlı olarak analiz edilmesi amaçlanmıştır. Çalışmada Nisan, Mayıs ve Haziran aylarına ait 12 farklı tarihli Sentinel-2 uydu görüntülerinden hesaplanan Normalize Fark Bitki İndeksi (NDVI) ve Normalize Fark Nem İndeksi (NDMI) kullanılmıştır. Ayrıca, istatiksel analizlerde kullanmak amacıyla tarım alanı olduğu bilinen 100 adet nokta formatında yer gerçeği vektör verilerinden yararlanılmıştır. NDVI ve NDMI verilerinin istatistiksel analizinde normallik testleri ve korelasyon analizleri gerçekleştirilmiştir. Veri setinin normal dağılım gösterip göstermediği çarpıklık-basıklık değerleri, histogramlar ve Shapiro–Wilk testi sonuçları ile kontrol edilmiştir. Buna göre verilerin normal dağılmadığı tespit edilmiş ve korelasyon analizlerinde Spearman'ın korelasyon katsayısı hesaplanmıştır. Analiz sonuçları, tüm dönemler için NDVI ve NDMI arasında pozitif ve yüksek düzeyde anlamlı bir ilişki bulunduğunu ortaya koymuştur. En yüksek korelasyon katsayıları 20 Mayıs 2025 (ρ=0.96) ve 23 Mayıs 2025 (ρ=0.96) tarihlerinde elde edilmiştir. Elde edilen bulgular, Nisan–Haziran büyüme dönemi boyunca bitki örtüsü ve nem göstergeleri arasında anlamlı ve tutarlı bir ilişki olduğunu göstermektedir. Bu ilişki, çok zamanlı uydu uzaktan algılama verilerinin ürün gelişimi takibi, sulama planlaması ve sürdürülebilir su yönetimi süreçlerinde karar destek mekanizmalarını güçlendirme potansiyelini vurgulamaktadır.

Anahtar Kelimeler: Bitki Örtüsü İzleme, CBS, Çok Zamanlı Analiz, Hassas Tarım, Uzaktan Algılama.

ABSTRACT

Satellite-based remote sensing has become a fundamental tool in precision agriculture due to its ability to provide continuous, objective, and large-scale data for monitoring vegetation and soil conditions. This study aims to analyze, on a multi-temporal basis, the relationship between

vegetation dynamics and moisture content in agricultural areas. The study utilized Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) values derived from 12 Sentinel-2 satellite images acquired between April, May, and June 2025. Additionally, 100 ground truth vector points known to represent agricultural land were used for statistical analyses. Normality tests and correlation analyses were performed on the NDVI and NDMI datasets. The distribution of the data was assessed using skewness–kurtosis values, histograms, and the Shapiro–Wilk test. Since the datasets did not exhibit normal distribution, Spearman's rank correlation coefficient (ρ) was calculated to examine the correlation. The analysis results revealed a positive and highly significant correlation between NDVI and NDMI across all periods. The highest correlation coefficients were obtained on 20 May 2025 (ρ=0.96) and 23 May 2025 (ρ=0.96). The findings demonstrate that there is a significant and consistent relationship between vegetation vigor and moisture content throughout the April–June growing season. This relationship highlights the potential of multi-temporal satellite remote sensing data to strengthen decision-support mechanisms for crop growth monitoring, irrigation scheduling, and sustainable water resource management in precision agriculture.

Keywords: GIS, Multi-Temporal Analysis, Precision Agriculture, Remote Sensing, Vegetation Monitoring.

GİRİŞ

Hassas tarım teknolojileri, veri odaklı yaklaşımlar ile mahsul, toprak ve kaynak yönetimini optimize ederek üretimde verimliliği artırmayı, aynı zamanda işletme maliyetlerini düşürmeyi ve çevresel etkiyi en aza indirmeyi de amaçlamaktadır (Saha vd., 2025). Bu kapsamda değerlendirildiğinde hassas tarım, tarımsal üretimi artırmak ve girdi kayıplarını en aza indirmek amacıyla girdilerin en uygun şekilde yönetilmesini sağlayan bir teknoloji bütününün uygulanmasını gerektirmektedir. Hassas tarımın önemli faktörlerinden biri, bitki örtüsü sağlığını ve durumunu izleyebileceğimiz uzaktan algılama teknolojileridir. Son yıllarda hassas tarımda uzaktan algılama teknolojilerinin kullanımı önemli ölçüde artmıştır. Mekânsal, spektral ve zamansal açıdan yüksek çözünürlüklü uydu görüntülerinin günümüzde daha erişilebilir hale gelmesi özellikle mahsul izleme, sulama planlaması, besin yönetimi, hastalık ve zararlı takibi ile verim tahmini gibi çok sayıda hassas tarım uygulamasında uzaktan algılamanın kullanımını önemli ölçüde teşvik etmiştir (Sishodia vd., 2020; Giovos vd., 2021).

Hassas tarımda ve genel olarak tarımda kullanılan uzaktan algılama sistemleri, sensör platformuna ve sensör tipine göre sınıflandırılmaktadır. Bu kapsamda kullanılan sensörler genellikle uydu, hava ve yer tabanlı platformlara monte edilmektedir. Her ne kadar bulut örtüsü, yüksek maliyet ve isteğe bağlı görüntüleme çözümleri bakımından dezavantajları bulunsa da günümüzde geniş kapsama alanları ve yüksek çözünürlüklü veriler sunan uydu tabanlı uzaktan algılama sistemleri tarımsal uygulamalarda aktif bir şekilde kullanılmaktadır (Sishodia vd., 2020).

Bitki örtüsü indeksleri, birden fazla spektral bantta ölçülen yansıma değerlerini bir araya getirerek bitkinin büyüme durumu, canlılığı, biyokütlesi ve klorofil miktarı gibi özelliklerini değerlendirmeye imkân veren matematiksel ifadelerdir. Bitki sağlığı hakkında nicel veriler sağlayan bu indekslerin haritalanması, tarım alanlarındaki mekânsal ve zamansal değişkenliği ortaya koymak açısından hassas tarım uygulamalarında kritik önem taşımaktadır (Sishodia vd., 2020; Radočaj vd., 2023). Bu bitki örtüsü indeksleri içerisinde multispektral sensör tabanlı hesaplanan NDVI, hassas tarımda en sık kullanılan bitki örtüsü indeksidir (Giovos vd., 2021; Radočaj vd., 2023). Bunun yanı sıra NDMI, bitkilerdeki nem, su stresi durumu ve sulama altındaki alanları tespit etmek amacıyla kullanılan bir indekstir. Bu indeks sonucu elde edilen nicel veriler ile tarım alanları farklı su ihtiyacı olan bölgelere ayrılıp, gerektiğinde hassas

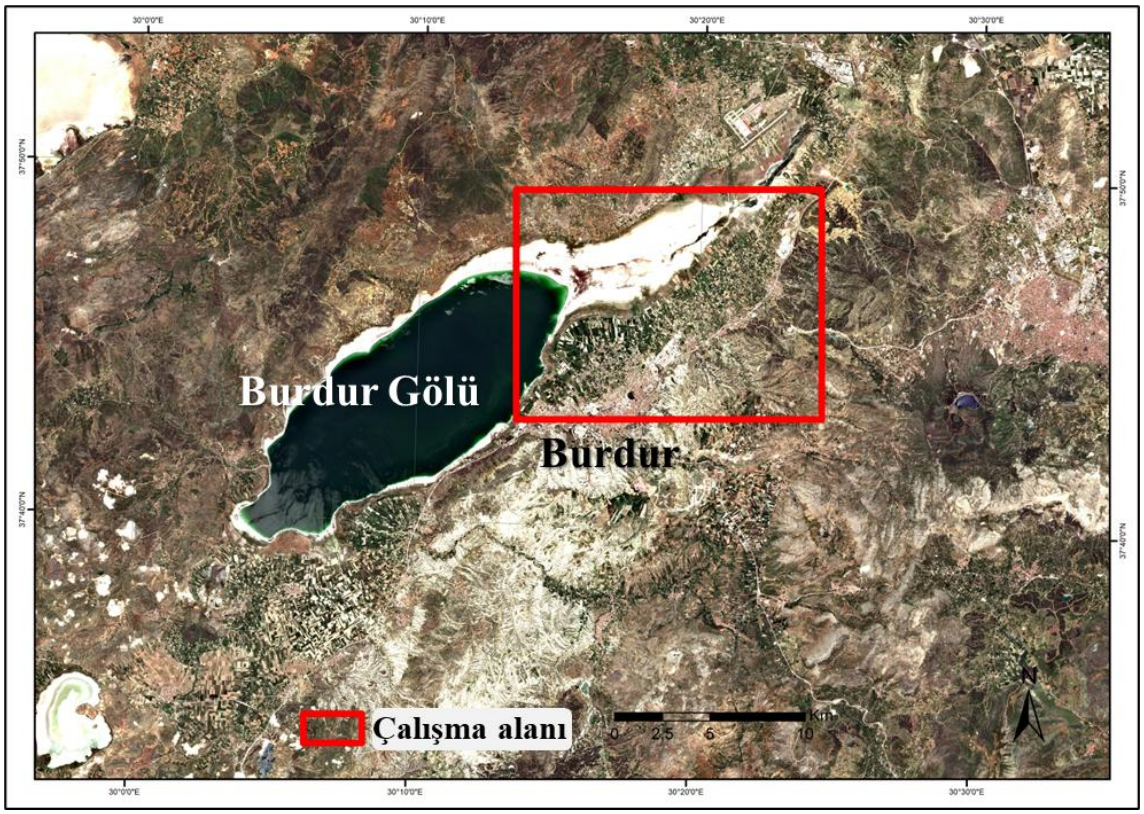
sulama uygulamaları kapsamında planlama çalışmaları yapılabilmektedir (Gaznayee vd., 2023; Koohikeradeh vd., 2025). NDVI ve NDMI, bitki örtüsü sağlığını nicel olarak ortaya koyarak tarla içinde ek izleme veya yönetimsel müdahale gerektirebilecek alanların belirlenmesine önemli katkılar sağlamaktadır. NDVI ve NDMI'nın eşzamanlı analizi, bitki sağlığı ve toprak nemindeki zamansal eğilimlerin kapsamlı bir şekilde anlaşılmasını sağlar; NDVI bitki örtüsü canlılığını ortaya koyarken, NDMI ise bitki ve toprak nemi içeriğine ilişkin önemli bilgiler sunar. NDVI ve NDMI haritalarını oluşturmak için uydu görüntülerini kullanmak, zaman içinde büyük alanların izlenmesine imkân tanıyan uygun maliyetli ve verimli uygulamalardır (Varouchakis vd., 2025). Tarım alanlarında nicel veriler sunma kabiliyetine sahip bu iki indeks kullanılarak yapılan önemli çalışmalar bulunmaktadır. Bu kapsamda yapılan çalışmalara Gaznayee vd. (2023) tarafından ideal sulama sistemi performans senaryolarını değerlendirmek ve Bchir ve Masmoudi-Charfi (2024) tarafından bitki örtüsü ve nem indekslerini tahmin etmek ve haritalamak amacıyla gerçekleştirilen araştırmalar örnek olarak verilebilir.

Günümüzde bitki örtüsü sağlığı ile nem koşullarının birlikte değerlendirilmesi, tarımsal üretim süreçlerinin izlenmesi ve optimize edilmesinde kritik bir öneme sahiptir. Bu bağlamda, NDVI ve NDMI gibi spektral indekslerin çok zamanlı olarak incelenmesi, bitki gelişimi ile nem dinamikleri arasındaki etkileşimin daha kapsamlı ve nicel bir biçimde ortaya konmasına olanak tanımaktadır. Özellikle Sentinel-2 gibi yüksek konumsal, zamansal ve spektral çözünürlüklere sahip uydu platformları, tarım alanlarının büyüme dönemi boyunca izlenmesi için önemli fırsatlar sunmaktadır. Bu çalışma, Nisan–Haziran dönemine ait çok zamanlı NDVI ve NDMI verilerini temel alarak tarımsal alanlardaki bitki örtüsü değişimleri ile nem içeriği arasındaki ilişkiyi istatistiksel olarak incelemeyi amaçlamakta; böylece uzaktan algılama temelli indekslerin sulama yönetimi, ürün gelişimi izleme ve sürdürülebilir hassas tarım uygulamalarındaki karar destek süreçlerine katkı potansiyelini ortaya koymaktadır.

MATERYAL VE YÖNTEM

Çalışma alanı ve veri

Çalışma alanı Burdur şehir merkezinin kuzeyinde ve Burdur Gölü'nün doğusunda yer almaktadır (Şekil 1). Türkiye'nin güneybatısında ve Akdeniz Bölgesi'nin batısında yer alan Burdur İli, 29° 24' ve 30° 53' doğu boylamları ile 36° 53' ve 37° 40' kuzey enlemleri arasında konumlanmaktadır. Burdur ilinin güneyinde Antalya, batısında Denizli, güneybatısında Muğla, doğu ve kuzeyinde Isparta ve Afyonkarahisar illeri yer almaktadır. Ayrıca Burdur'un güney kesiminde Toros Dağları'nın uzantıları yer alırken, ilin önemli bir bölümü kapalı havza niteliğindeki Burdur Gölü ve çevresindeki plato ve tepelerden oluşmaktadır (Burdur Valiliği, 2021).



Şekil 1. Çalışma alanı

Burdur'da kışlar soğuk ve yağışlı, yazlar sıcak ve kurak geçmekte olup geçiş iklimi özellikleri göstermektedir. Yağışların büyük bölümü kış aylarında gerçekleşmekte; ilk donlar Kasım'da, son donlar ise Nisan ayının ikinci yarısında görülmektedir (Burdur İl Tarım ve Orman Müdürlüğü, 2025). 1932–2024 uzun dönem verilerine göre en düşük ortalama sıcaklık Ocak ayında 2.60 °C, en yüksek ortalama sıcaklık ise Temmuz–Ağustos döneminde 24.60 °C'dir. Yıllık ortalama sıcaklık 13.30 °C, ortalama yıllık yağış miktarı 428.10 mm ve yağışlı gün sayısı 88.20 olarak belirlenmiştir (MGM, 2025). Burdur Havzası'nda toprakların önemli bir bölümünü kestanerengi topraklar oluşturmakta (%22.65) olup bu topraklar Burdur Gölü çevresinde kumtaşı, kiltaşı, çamurtaşı ve konglomera üzerinde gelişmiş ve organik maddece zengindir. Ayrıca gölün güneybatısında yaygın kırmızı kahverengi orman toprakları ile ayrışma kökenli kireçsiz kahverengi orman toprakları da havzanın karakteristik diğer toprak gruplarıdır (Tarım ve Orman Bakanlığı, 2020).

Çalışmada kullanılan temel veri seti Sentinel-2 uydu görüntüleridir (Çizelge 1). Sentinel-2, geniş kapsama alanı, yüksek çözünürlüklü ve multispektral görüntüleme ile özellikle toprak, su ve bitki örtüsünün izlenmesine yönelik çalışmalarda kullanılmaktadır.

Çizelge 1. Sentinel-2 uydusunun mekânsal ve spektral özellikleri

Spektral Bant	Merkezi Dalga Boyu (nm*)	Mekânsal Çözünürlük (m**)
B1: Ultra mavi (kıyı, aerosol)	443	60
B2: Mavi	490	10
B3: Yeşil	560	10
B4: Kırmızı	665	10
B5: Kırmızı kenar 1	705	20
B6: Kırmızı kenar 2	740	20
B7: Kırmızı kenar 3	783	20
B8: Yakın kızılötesi (NIR)	842	10
B8A: Yakın kızılötesi-dar	865	20
B9: Su buharı	945	60
B10: Kısa dalga kızılötesi (SWIR)	1375	60
B11: Kısa dalga kızılötesi (SWIR)	1610	20
B12: Kısa dalga kızılötesi (SWIR)	2190	20

**nanometre ve **metre*

Bu çalışma kapsamında Nisan, Mayıs ve Haziran aylarına ait 12 farklı tarihli Sentinel-2 uydu görüntüleri kullanılmıştır (Çizelge 2).

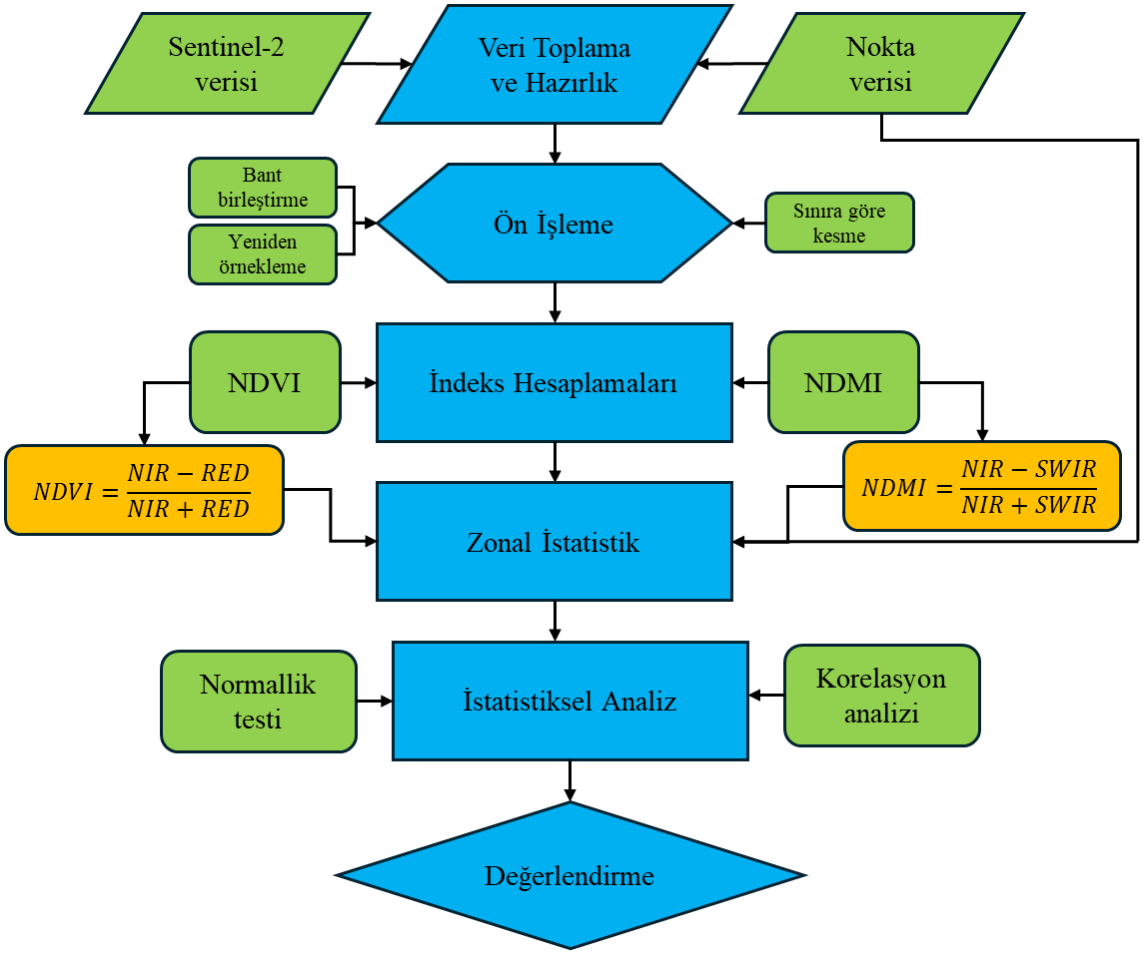
Çizelge 2. Çalışmada kullanılan Sentinel-2 uydu görüntüleri

Sentinel-2 Platformu	Görüntü Tarihi
S2A_MSIL2A_T36STG	10 Nisan 2025
S2C_MSIL2A_T36STG	15 Nisan 2025
S2B_MSIL2A_T36STG	20 Nisan 2025
S2B_MSIL2A_T36STG	23 Nisan 2025
S2C_MSIL2A_T36STG	15 Mayıs 2025
S2A_MSIL2A_T36STG	20 Mayıs 2025
S2B_MSIL2A_T36STG	23 Mayıs 2025
S2C_MSIL2A_T36STG	28 Mayıs 2025
S2C_MSIL2A_T36STG	04 Haziran 2025
S2A_MSIL2A_T35SQB	09 Haziran 2025
S2C_MSIL2A_T35SQB	14 Haziran 2025
S2A_MSIL2A_T35SQB	19 Haziran 2025

Çalışmada kullanılan bir diğer veri, istatistiksel analizlerde kullanmak amacıyla tarım alanı olduğu bilinen 100 adet nokta verisidir. Bu veri, yüksek çözünürlüklü Google Earth Pro ve Sentinel-2 uydusunun yanlış renk kombinasyonları üzerinden kontrol edilerek CBS ortamında vektör veri olarak üretilmiştir.

Yöntem

Çalışma veri toplama ve hazırlık, ön işleme, indeks hesaplamaları, zonal istatistik, istatiksel analizler ve değerlendirme aşamalarından oluşmaktadır (Şekil 2).



Şekil 2. İş akışı

Çalışmanın ilk aşaması olan veri toplama ve hazırlık aşamasında ilgili tarihlere ait Sentinel-2 verileri, Avrupa Birliği Uzay Programı Copernicus'tan indirilmiştir. Bu aşamada, çalışma alanındaki tarım alanları yüksek çözünürlüklü Google Earth Pro üzerinden belirlenmiştir (.kml formatında). Daha sonra bu noktaların CBS ortamında projeksiyon dönüşümleri gerçekleştirilmiş ve shapefile (.shp) formatına dönüştürülmüştür. Bu noktalar Sentinel-2'nin doğru ve yanlış renk kombinasyonları üzerinden kontrol edilerek gerekli düzeltmeler sağlanmıştır. Ön işleme aşamasında görüntülere sırasıyla yeniden örnekleme (resample), bant birleştirme (composite bands) ve alan sınırına göre kesme (clip) işlemleri uygulanmıştır. Bu aşamada, özellikle mekânsal çözünürlüğü daha düşük olan SWIR bandı (20 m), 10 m

çözünürlüklü bantlarla (kırımızı, yeşil, mavi ve yakın kızılötesi) uyumluluk sağlamak üzere yeniden örneklenmiştir. Ayrıca ön işleme aşamasında ek bir atmosferik düzeltme veya bulut giderme işlemi uygulanmamıştır. Bunun nedeni, kullanılan verilerin hâlihazırda atmosferik olarak düzeltilmiş L2A düzeyinde ürünler olması ve veri indirme sürecinde %10 bulutluluk eşiğinin filtreleme kriteri olarak belirlenmesidir. Çalışmanın indeks hesaplamaları aşamasında, Eşitlik 1 ve Eşitlik 2'de verilen NDVI (Rouse vd., 1974) ve NDMI (Gao, 1996) indeksleri kullanılmıştır.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

$$NDMI = \frac{NIR - SWIR}{NIR + SWIR} \quad (2)$$

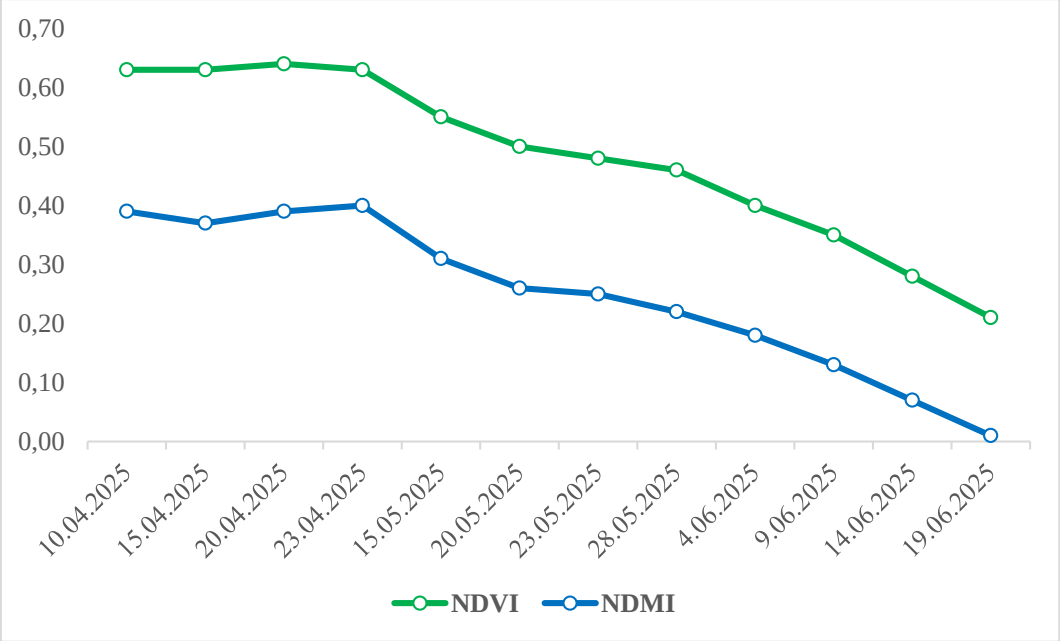
burada RED görünür bölgedeki kırmızı, NIR yakın kızılötesi ve SWIR ise kısa dalga kızılötesi bölgedeki yansımadır. NDVI, yaygın olarak kullanılan bitki örtüsü indekslerinden biri olup -1 ve +1 arasında bir değer almaktadır. NDVI için negatif değerler su kütleleri varlığına işaret ederken, sıfıra yakın değerler çıplak toprak, kaya, kuraklık veya zararlılar nedeniyle meydana gelen bitki örtüsü yokluğunu göstermektedir. NDVI'da olduğu gibi -1 ve +1 arasında bir değer alan NDMI ise, bitki örtüsündeki nem durumunu tespit etmek için kullanılmaktadır. Buradaki SWIR bant, bitki örtüsünün su içeriğine duyarlı olup bitkilerdeki su stresinin güvenilir bir göstergesi olarak kullanılmaktadır (Nicoletti vd., 2024; Varouchakis vd., 2025).

Yer gerçeği olarak kullanılan 100 adet noktaya ait NDVI ve NDMI değerleri zonal istatistik aracı kullanarak çıkarılmıştır. Daha sonra bu noktalar istatiksel analizlerde kullanmak üzere excel dosyası olarak düzenlenerek kaydedilmiştir. Çalışmanın istatiksel analiz aşamasında, öncelikle verilerin normal dağılım gösterip göstermediği test edilmiştir. Bu kapsamda her bir tarih ve indeks için histogramlar, çarpıklık-basıklık değerleri ve Shapiro-Wilk testi hesaplamaları gerçekleştirilmiştir. Bu işlem adımından sonra elde edilen değerlere göre her ne kadar bazı tarihlerde veri seti NDVI ve NDMI için normal dağılım göstermiş olsa da tamamı üzerinden değindirildiğinde genel olarak normal dağılım göstermediği belirlenmiştir. Bu nedenle NDVI ve NDMI arasındaki ilişkinin belirlenmesinde Spearman's korelasyon katsayısı hesaplanmıştır. Makuya vd. (2024) tarafından yapılan çalışmada, değişkenler arasında doğrusal olmayan bir ilişki belirlenmiş ve bu nedenle Spearman'ın korelasyon katsayısı kullanılmıştır. Spearman'ın korelasyon katsayısı, iki değişken arasındaki ilişkiyi ve bu ilişkinin yönünü belirlemede kullanılan parametrik olmayan bir yöntemdir. Bu analiz türü, özellikle mekânsal bilimler alanında araştırmacılar tarafından sıkça tercih edilmektedir (Çubukçu, 2015). Çalışmanın son aşamasında, iki değişken arasındaki ilişkinin zaman içerisindeki değişimi analiz edilerek bitki örtüsünün dönemsel dinamikleri ile yüzey nem koşulları arasındaki ilişki sistematik olarak değerlendirilmiştir.

BULGULAR VE TARTIŞMA

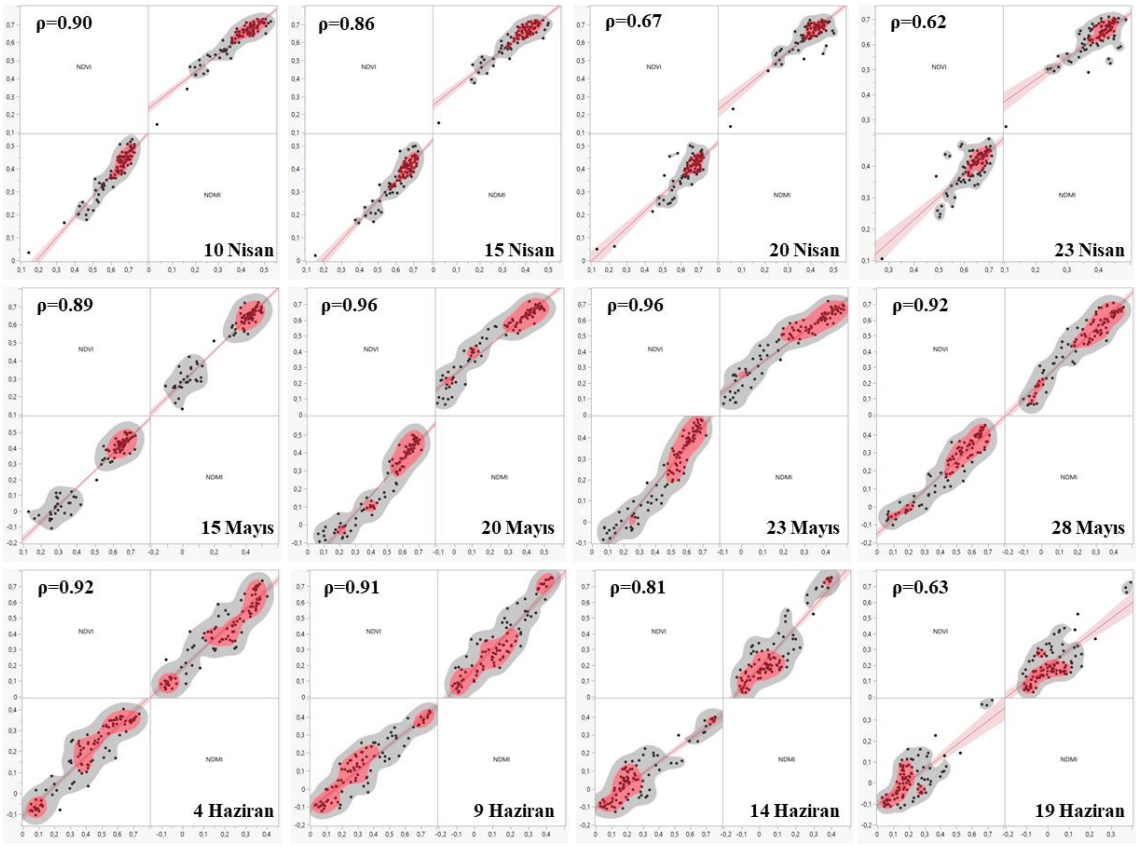
Çalışma alanında yürütülen çok zamanlı analiz sonucunda, 10 Nisan-19 Haziran 2025 dönemine ait NDVI ve NDMI ortalama değerlerinde belirgin bir azalma eğilimi tespit edilmiştir (Şekil 3). Şekil incelendiğinde, en yüksek ortalama NDVI değerinin 20 Nisan 2025 tarihinde, en düşük NDVI değerinin ise 19 Haziran 2025 tarihli analiz sonucunda elde edildiği görülmektedir. Örnek tarım alanlarındaki en yüksek ortalama NDMI değeri 23 Nisan 2025'te,

en düşük NDMI değeri ise NDVI ile benzer şekilde 19 Haziran 2025 tarihinde kaydedilmiştir. Çalışma alanındaki ürün türleri bilinmemekle birlikte, alanın tarımsal kullanımda olduğu göz önünde bulundurulduğunda her iki göstergedeki paralel düşüş; bitki örtüsünün mevsimsel gelişim döngüsüne, artan su stresine veya vejetasyon yoğunluğunun azalmasına işaret edebilecek bir durum olarak değerlendirilebilir. Ayrıca NDVI'daki kademeli azalma bitki canlılığının ve yeşil biyokütlenin zaman içerisinde gerilediğini gösterirken, NDMI'daki daha belirgin düşüş ise toprak ve bitki nemi koşullarının aynı dönemde daha hızlı zayıfladığını ortaya koymaktadır. Bu bulgular, çalışma alanındaki NDVI-NDMI eğilimlerinin tarımsal dinamikler ve alanın olası su gereksinimleri hakkında önemli ipuçları sunduğunu göstermektedir.



Şekil 3. Ortalama NDVI ve NDMI değerleri

Çalışma kapsamında gerçekleştirilen istatiksel analizler sonucunda, 12 farklı tarihli NDVI-NDMI korelasyon analizi grafikleri elde edilmiştir (Şekil 4). Analiz sonuçları, çalışma alanında bitki ve nem içeriği ilişkilerinin izlenmesi açısından NDVI ve NDMI indekslerinin birlikte değerlendirilmesinin önemli bir avantaj sağladığını göstermektedir. Böylece tarımsal üretim süreçlerinde stres tespiti, sulama planlaması ve verim tahmini gibi uygulamalara katkı sunabilecek bir izleme yaklaşımı ortaya çıkmaktadır.



Şekil 4. Dönemlere ait korelasyon grafikleri

NDVI ve NDMI arasındaki korelasyonu gösteren çok zamanlı grafikler incelendiğinde, Nisan–Haziran döneminde bitki örtüsü ve nem koşulları arasındaki ilişkinin oldukça düzenli bir zamansal desen izlediği görülmektedir. Bu kapsamda değerlendirildiğinde genel olarak tüm tarihlerde pozitif ve yüksek düzeyde anlamlı bir ilişki olduğu tespit edilmiştir (ρ=0.62-0.96). Nitekim tarım alanlarında yapılan bir çalışmada Bchir ve Masmoudi-Charfi (2024), bu iki indeks arasında yüksek korelasyon olduğunu ortaya koymuştur. Ayrıca araştırmacılar tarafından bitki örtüsünün olgunlaşma döneminde NDMI'nın nem değişimlerini daha iyi tespit edebildiği ve bu dönemde korelasyonun düşüş eğilimine girdiği belirtilmiştir. Bir başka çalışmada ise kentsel yeşil alanda çok zamanlı analiz sonucunda NDVI ve NDMI arasında pozitif yönlü yüksek bir ilişki olduğu ve farklı yıllardaki değişkenliğin sıcaklıktan kaynaklanmış olabileceği değerlendirilmiştir (Strashok vd., 2022). Çalışmadan elde edilen bulgular literatürde yer alan benzer araştırma sonuçları ile paralellik göstermektedir. Bu kapsamda değerlendirildiğinde NDVI ve NDMI'nın eşzamanlı analizinin, bitki sağlığı ve nem durumundaki zamansal eğilimlerin kapsamlı bir şekilde anlaşılmasını sağlayabileceği ortaya konmuştur. Varouchakis vd. (2025), NDVI'nın bitki örtüsü canlılığını; NDMI'nın ise nem içeriğini ortaya koymada tamamlayıcı bir role sahip olduğunu belirtmiştir. Bu kapsamda her iki indeksin birlikte kullanımı, özellikle rehabilite edilen alanlarda bitki örtüsü sağlığının izlenmesinde önemli bir araç olarak vurgulanmıştır. Bu bulgular, mevcut çalışmalarda gözlenen pozitif ve güçlü korelasyonlar ile uyumlu olup benzer ekolojik süreçlerin farklı çalışma alanlarında da geçerli olabileceğini göstermektedir.

Çalışmadan elde edilen bulgular, Nisan döneminde alandaki vejetasyon heterojenliği nedeniyle korelasyonun orta ve yüksek (ρ=0.62-0.90), Mayıs döneminde yoğun bitki örtüsü ve yüksek nem içeriği nedeniyle NDVI-NDMI arasında maksimum korelasyon (ρ=0.89-0.96) ve Haziran döneminde ise sıcaklığın belirgin bir şekilde artması ve alandaki bazı bitki örtüsü için hasat

zamanının gelmesi; dolasıyla kuruma ve doygunluk etkisi gibi nedenlerle zayıflayan bir korelasyon (ρ=0.63-0.92) olduğunu göstermiştir. Bu bulgular, NDVI ve NDMI arasındaki ilişkinin bitkilerin fenolojik evreleri ile yakından ilişkili olduğunu ve su stresinin arttığı dönemlerde bu ilişkinin zayıfladığını ortaya koymaktadır. Nitekim Gaznayee vd. (2023) tarafından yapılan çalışmada uzaktan algılama tabanlı NDVI ve NDMI analizlerinin, alan düzeyinde sulama suyunun izlenmesi ile su gereksinimlerinin mekânsal ve zamansal dağılımına ilişkin değerli bilgiler sağlayabildiği; ayrıca nem içeriği ile NDVI değerleri arasında anlamlı ilişkiler bulunduğu tespit edilmiştir. Bu doğrultuda elde edilen bulgular, NDVI ve NDMI'nın eşzamanlı kullanımının bitki-su etkileşimlerinin çözümlemesinde bütüncül ve güvenilir bir çerçeve sunduğunu ortaya koymakta; böylece tarımsal su yönetimi, bitki sağlığının izlenmesi ve ekosistem dinamiklerinin değerlendirilmesine yönelik gelecekte yapılacak çalışmalara önemli bir bilimsel temel sağlamaktadır.

SONUÇ

Uydu tabanlı uzaktan algılama teknolojisinin hassas tarım uygulamaları kapsamında kullanımına odaklanan bu çalışmada, Nisan–Haziran dönemine ait çok zamanlı Sentinel-2 uydu görüntülerinden üretilen NDVI ve NDMI kullanılarak tarım alanlarında bitki örtüsü dinamikleri ile nem içeriği arasındaki ilişki analiz edilmiştir. Analiz sonuçları, tüm çalışma dönemleri boyunca NDVI ve NDMI indeksleri arasında pozitif ve yüksek düzeyde anlamlı bir ilişki bulunduğunu göstermiştir. Özellikle 20 Mayıs 2025 ve 23 Mayıs 2025 tarihlerinde elde edilen değerler (ρ=0.96), bitki örtüsü gelişimi ile yüzey nemi arasındaki güçlü korelasyonu açıkça ortaya koymaktadır. Elde edilen bulgular, büyüme sezonu boyunca bitki sağlığı ve nem dinamiklerinin uyumlu bir şekilde değiştiğini ve her iki indeksin tarımsal izleme süreçlerinde birlikte kullanılmasının karar verme süreçlerine önemli katkılar sağlayabileceğini göstermektedir. Çalışmanın sonuçları, ürün gelişiminin izlenmesi, sulama zamanının belirlenmesi ve su kaynaklarının daha verimli kullanılmasına yönelik planlamalarda uydu tabanlı uzaktan algılama verilerinin yüksek bir potansiyel taşıdığını göstermektedir. Gelecek çalışmalarda, belirli ve farklı ürün türlerine yönelik karşılaştırmalı analizlerin yapılması, meteorolojik verilerin çalışmalara daha etkin bir şekilde entegrasyonu ve makine öğrenmesi tabanlı modellerle ilişki düzeylerinin daha ayrıntılı olarak incelenmesi, elde edilen bulguların hem doğruluğunu hem de uygulama alanlarını genişleteceği değerlendirilmektedir.

KAYNAKLAR

Bchir, A., & Masmoudi-Charfi, C. (2024). Estimating and Mapping NDVI and NDMI Indexes by Remote Sensing of Olive Orchards in Different Tunisian Regions. In: Ksibi, M., et al. Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions (3rd Edition). EMCEI 2021. Advances in Science, Technology & Innovation. *Springer*, Cham. https://doi.org/10.1007/978-3-031-43922-3_116

Burdur Valiliği, (2021). *Burdur İl Afet Risk Azaltma Planı*. Erişim adresi http://www.burdur.gov.tr/burdur-il-afet-risk-azaltma-plani. Son Erişim 18 Kasım 2025.

Burdur İl Tarım ve Orman Müdürlüğü, (2025). *İklim Durumu ve Nüfus Yapısı*. Erişim adresi https://burdur.tarimorman.gov.tr/Sayfalar/Detay.aspx?SayfaId=13. Son Erişim 18 Kasım 2025.

Çubukçu, K. M. (2015). Planlamada ve coğrafyada temel istatistik ve mekânsal istatistik. Nobel Akademik Yayıncılık.

Gao, B. C. (1996). NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. Remote sensing of environment, 58(3), 257-266.

Gaznayee, H. A. A., Zaki, S. H., Al-Quraishi, A. M. F., Aliehsan, P. H., Hakzi, K. K., Razvanchy, H. A. S., Riksen, M., & Mahdi, K. (2023). Integrating Remote Sensing Techniques and Meteorological Data to Assess the Ideal Irrigation System Performance Scenarios for Improving Crop Productivity. *Water*, 15(8), 1605. https://doi.org/10.3390/w15081605

Giovos, R., Tassopoulos, D., Kalivas, D., Lougkos, N., & Priovolou, A. (2021). Remote Sensing Vegetation Indices in Viticulture: A Critical Review. *Agriculture*, 11(5), 457. https://doi.org/10.3390/agriculture11050457

Koohikeradeh, E., Jose Gumiere, S., & Bonakdari, H. (2025). NDMI-Derived Field-Scale Soil Moisture Prediction Using ERA5 and LSTM for Precision Agriculture. *Sustainability*, 17(6), 2399. https://doi.org/10.3390/su17062399

Makuya, V., Tesfuhuney, W., Moeletsi, M. E., & Bello, Z. (2024). Assessing the Impact of Agricultural Drought on Yield over Maize Growing Areas, Free State Province, South Africa, Using the SPI and SPEI. *Sustainability*, 16(11), 4703. https://doi.org/10.3390/su16114703

MGM, (2025). *Resmi İklim İstatistikleri*. Erişim adresi https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=BURDUR. Son Erişim 18 November 2025.

Nicoletti, R., De Masi, L., Migliozzi, A., & Calandrelli, M. M. (2024). Analysis of Dieback in a Coastal Pinewood in Campania, Southern Italy, through High-Resolution Remote Sensing. *Plants*, 13(2), 182. https://doi.org/10.3390/plants13020182

Radočaj, D., Šiljeg, A., Marinović, R., & Jurišić, M. (2023). State of Major Vegetation Indices in Precision Agriculture Studies Indexed in Web of Science: A Review. *Agriculture*, 13(3), 707. https://doi.org/10.3390/agriculture13030707

Rouse Jr, J. W., Haas, R. H., Deering, D. W., Schell, J. A., & Harlan, J. C. (1974). Monitoring the vernal advancement and retrogradation (green wave effect) of natural vegetation (No. E75-10354).

Saha, S., Kucher, O. D., Utkina, A. O., & Rebouh, N. Y. (2025). Precision agriculture for improving crop yield predictions: a literature review. *Frontiers in Agronomy*, 7, 1566201.

Sishodia, R. P., Ray, R. L., & Singh, S. K. (2020). Applications of Remote Sensing in Precision Agriculture: A Review. *Remote Sensing*, 12(19), 3136. https://doi.org/10.3390/rs12193136

Strashok, O., Ziemiańska, M., & Strashok, V. (2022). Evaluation and Correlation of Sentinel-2 NDVI and NDMI in Kyiv (2017–2021). *Journal of Ecological Engineering*, 23(9).

Tarım ve Orman Bakanlığı, (2020). *Burdur Havzası Nehir Havza Yönetim Planı Hazırlanması Projesi Nehir Havza Yönetim Planı Nihai Raporu.* Erişim adresi https://www.tarimorman.gov.tr/SYGM/Belgeler/NEH%C4%B0R%20HAVZA%20Y%C3%96NET%C4%B0M%20PLANLARI%2028.12.2022/Burdur%20Havzas%C4%B1%20NHYP%2028.12.2018/BUN_NHYP%20Nihai%20Raporu.pdf?utm. Son Erişim 18 November 2025.

Varouchakis, E. A., Komnitsas, K., & Galetakis, M. (2025). Spatiotemporal Analysis of Vegetation Health and Moisture Dynamics in Rehabilitated Mining Quarries Using Satellite Imagery. *Environmental Processes*, 12(3), 45. https://doi.org/10.1007/s40710-025-00781-3

HOST INTERACTIONS AND DAMAGE MECHANISMS OF ERIOPHYID MITES (ACARI: ERIOPHYIDAE)

ERIOPHYID AKARLARIN (ACARİ: ERİOPHYİDAE) KONUKÇU ETKİLEŞİMLERİ VE ZARAR MEKANİZMALARI

Nihal KILIÇ

Tekirdağ Namık Kemal Üniversitesi, Ziraat Fakültesi, Bitki Koruma Bölümü, Tekirdağ, Türkiye

ORCID ID: https://orcid.org/0000-0002-7538-7444

Kübra KOÇ

Tekirdağ Namık Kemal Üniversitesi, Ziraat Fakültesi, Bitki Koruma Bölümü, Tekirdağ, Türkiye

ORCID ID: https://orcid.org/0009-0009-2442-3116

ÖZET

Eriophyid akarlar (Acari: Trombidiformes: Eriophyidae), mikroskobik boyutları, oldukça basitleşmiş vücut yapıları ve dar konukçu seçicilikleri nedeniyle bitkilerle ilişkili türler arasında dikkat çeker. Çoğu yalnızca tek bir bitki türünde yaşar ve bu durum onların bitkiye yüksek düzeyde uyum sağladığını gösterir. Çok küçük olmaları yalnızca fark edilmelerini zorlaştırmaz; aynı zamanda genç ve savunması düşük bitki dokularına hızla yerleşmelerine imkân verir. Bu özel yaşam şekli, oluşturdukları zarar tiplerinin gelişimini, şiddetini ve bitki fizyolojisine etkilerini doğrudan belirler. Bu çalışma, eriophyid akarların konukçu seçimini, başlıca zarar şekillerini ve bu zararların tarım ile doğal ekosistemlerdeki sonuçlarını bütüncül bir bakışla ele almaktadır.

Gall oluşturan türler, bitkinin büyüme noktalarında anormal doku gelişimine neden olarak sürgünlerin şeklini ve işlevini bozar. Söğütte *Aceria salicis* sürgün uçlarında kozalak benzeri yapılar oluşturur; bu yapılar yeni sürgün gelişimini sınırlar ve yıllık büyümeyi zayıflatır. Kuş üzümünde *Cecidophyopsis ribis* tomurcuk içini doldurarak çiçeklenmeyi ve meyve tutumunu ciddi biçimde düşürür. Fındıkta *Phytoptus avellanae* kozalak şeklindeki tomurcuk deformasyonlarıyla sürgün gelişimini ve verimi olumsuz etkiler.

Eriophyid akarlar beslenme sırasında tükürükleriyle bitki dokularına kimyasal sinyaller iletir ve bu sinyaller bitkinin fitohormon dengesini değiştirir. Bu değişim, gall ve erinoz gibi anormal doku gelişimlerinin ortaya çıkmasına neden olur. Böylece akarlar, doğrudan bitkiyi öldürmeseler bile büyüme düzenini bozarak fizyolojik kapasitenin düşmesine yol açar. Erinoz oluşturan türlerde yaprak alt yüzeyinde keçemsi bir tabaka oluşur ve bu tabaka ışık geçişini azaltarak fotosentezi zayıflatır. Asmada *Colomerus vitis* hem erinoza hem de tomurcuk deformasyonlarına neden olur ve üzüm verimini azaltır. Gall oluşumu, akarların genç dokularda hücre bölünmesi ve farklılaşmasını değiştiren kimyasal sinyaller göndermesiyle başlar. Bitkinin

fitohormon dengesi değişir ve içi yumuşak, dışı koruyucu bir tabakayla çevrili özel bir yapı oluşur. Bu yapı akar için hem beslenme alanı hem de korunaklı bir mikrohabitat sağlar.

Eriophyid zararlarının en önemli yönü, bitkiyi öldürmeden fakat fizyolojik kapasitesini yavaş ve kalıcı biçimde azaltmalarıdır. Sürgün kısalması, çiçeklenme azalması, büyüme geriliği ve kalite düşüşü gibi biriken etkiler ekonomik kayıpları artırır. Bu nedenle erken teşhis, doğru tür belirlenmesi ve popülasyon değişimlerinin düzenli izlenmesi, entegre mücadele stratejilerinin başarısı için kritik öneme sahiptir.

Anahtar Kelimeler: Eriophyidae; konukçu seçiciliği, gal oluşumu, entegre mücadele.

ABSTRACT

Eriophyid mites (Acari: Trombidiformes: Eriophyidae) attract attention among plant-associated arthropods due to their microscopic size, highly simplified body structure, and narrow host specificity. Most species live on only a single plant species, which reflects their high level of adaptation to their hosts. Their extremely small size not only makes them difficult to detect but also enables them to settle rapidly on young and weakly defended plant tissues. This specialized lifestyle directly shapes the development, severity, and physiological impact of the damage they cause. This study provides an integrated overview of host selection in eriophyid mites, their main damage types, and the consequences of these damages for agricultural and natural ecosystems.

Gall-forming species cause abnormal tissue development at plant growth points, altering the shape and function of shoots. In willow, *Aceria salicis* produces cone-like structures at shoot tips that restrict new shoot formation and weaken annual growth. In currant, *Cecidophyopsis ribis* fills the interior of buds, markedly reducing flowering and fruit set. In hazelnut, *Phytoptus avellanae* induces cone-shaped bud deformities that hinder shoot development and decrease yield.

During feeding, eriophyid mites deliver chemical signals into plant tissues through their saliva, altering the plant's phytohormone balance. This shift leads to abnormal tissue developments such as galls and erinea. Thus, although they do not kill the plant directly, they disrupt normal growth and reduce physiological capacity over time. In erinea-forming species, a felt-like layer develops on the lower leaf surface, reducing light penetration and weakening photosynthesis. In grapevine, *Colomerus vitis* induces both erinea and bud deformities, lowering grape yield. Gall formation begins when mites send chemical signals that alter cell division and differentiation in young plant tissues. The plant's phytohormone balance changes, producing a structure with a soft, nutrient-rich interior and a protective outer layer. This structure provides both a feeding site and a sheltered microhabitat for the mite.

A major characteristic of eriophyid damage is that it weakens the plant gradually and persistently without causing direct mortality. Shortened shoots, reduced flowering, growth suppression, and quality loss collectively increase economic damage. Therefore, early detection, accurate species identification, and regular monitoring of population dynamics are essential for the success of integrated pest management strategies.

Keywords: Eriophyidae; host specificity, gall formation; integrated pest management

GİRİŞ

Eriophyoid akarlar (*Acari: Eriophyoidea*), bitkilerle sıkı ilişkili yaşam biçimleri, iki çift bacak taşımaları ve son derece küçülmüş vücut yapılarıyla fitofag eklembacaklılar içinde özel bir

grubu temsil eder (Lindquist et al., 1996). Bu akarlar, konukçu bitkilerde oluşturdukları belirti tiplerine bağlı olarak Türkçe literatürde yaygın biçimde "gal akarları", "erinoz akarları" ve "pas (bronzlaşma) akarları" olarak adlandırılmaktadır. Bu kullanım, eriophyoidlerin bitkilerde meydana getirdiği karakteristik zarar şekillerini doğrudan tanımlamaya yöneliktir.

Eriophyoidea üst grubunun en türce zengin familyası olan Eriophyidae, konukçu bitkinin epidermisi, tomurcukları ve iletim demetleri çevresinde beslenerek bitki fizyolojisini doğrudan etkileyen çok sayıda türü içerir. Bu etkileşimler yaprak deformasyonları, büyüme anomalileri, erinoz oluşumu, bronzlaşma ve özellikle gal gelişimi gibi belirgin belirtilerle ortaya çıkmakta; tarımsal üretimde ve doğal ekosistemlerde önemli ekonomik ve ekolojik kayıplara yol açmaktadır (de Lillo et al., 2018).

Son yıllarda yapılan çalışmalar, eriophyid akarların aşırı derecede sadeleşmiş morfolojik yapıları ve dünya genelindeki yetersiz örnekleme nedeniyle büyük ölçüde eksik tanımlandığını göstermektedir. Morfolojik olarak birbirine çok benzeyen türlerin klasik yöntemlerle ayırt edilmesi güçleşirken, moleküler çalışmalar birçok türün genetik olarak ayrışmış tür komplekslerinden oluştuğunu ortaya koymuştur (Amrine et al., 2003; Navia et al., 2010; Carew et al., 2009). Bu nedenle, tanımlanmış yaklaşık 4.400 eriophyoid türe karşın gerçek tür zenginliğinin çok daha yüksek olduğu kabul edilmektedir (Skoracka & Kuczyński, 2012).

Eriophyoid akarların en ayırt edici özelliklerinden biri, son derece dar konukçu seçiciliğidir. Küresel analizler, türlerin yaklaşık %80'inin yalnızca tek bir bitki türünde, %95'inin ise tek bir bitki cinsi içinde sınırlı kaldığını göstermektedir (Skoracka et al., 2010). Bu yüksek özgüllük, konukçu–fitofag ilişkileri ve gal oluşumu gibi karmaşık doku yanıtlarının anlaşılmasında Eriophyidae'yi önemli bir grup hâline getirmektedir.

Türkiye'de eriophyid akarlar üzerine yapılan çalışmalar çoğunlukla tarımsal ürünlerle sınırlıdır. Fındıkta *Phytoptus avellanae* (fındık kozalak akarı), bağlarda *Colomerus vitis,* zeytinde *Aceria oleae,* süs bitkilerinde ise *Eriophyes tiliae* gibi türler yaygın olarak rapor edilmiştir (Çobanoğlu, 2002; Akyazı & Ecevit, 2008; Bayram & Çobanoğlu, 2013). Buna karşın yabancı otlar ile doğal ve yarı doğal bitki örtüsü üzerindeki eriophyid faunası büyük ölçüde ihmal edilmiştir. Son yıllarda özellikle yabancı otlar üzerinde yapılan sınırlı çalışmalar, Türkiye'de çok sayıda yeni kayıt ve potansiyel yeni tür bulunduğuna işaret etmektedir (Denizhan et al., 2022).

Bu çalışma, Eriophyidae familyasındaki tür çeşitliliğini, konukçu bitki özgüllüğünü ve gal oluşumunun morfolojik, fizyolojik ve moleküler temellerini güncel literatür ışığında ele almaktadır.

TAKSONOMİ, FİLOGENİ VE TÜR ÇEŞİTLİLİĞİ

Eriophyoidea Üst Familyasının Taksonomik Konumu

Eriophyoid akarlar, *Acari* içinde *Acariformes* alt sınıfına bağlı *Trombidiformes* takımı içerisinde yer alan ve yalnızca iki çift bacağa sahip olmalarıyla diğer akar gruplarından belirgin biçimde ayrılan özel bir gruptur. Son derece küçülmüş ve sadeleşmiş morfolojik yapıları, bitki dokuları üzerinde ve içinde yaşamaya uyum sağlamış gelişimsel ve ekolojik bir özelleşmenin sonucu olarak değerlendirilmektedir (Lindquist et al., 1996). Bu özellikler, eriophyoidlerin hem tanılanmasını güçleştirmekte hem de sistematik çalışmalar açısından ayrı bir önem kazanmalarına neden olmaktadır.

Eriophyoidea üst familyası, güncel taksonomik sınıflandırmaya göre üç ana familyadan oluşmaktadır: *Eriophyidae, Phytoptidae* ve *Diptilomiopidae*. Bu aileler arasında *Eriophyidae,* tür ve cins sayısı bakımından açık ara en geniş grubu oluşturmakta ve aynı zamanda ekonomik

önemi en yüksek olan eriophyoid türlerin büyük çoğunluğunu barındırmaktadır (de Lillo et al., 2018).

Eriophyidae Familyasının Morfolojik Tanı Kriterleri

Eriophyid akarlar, ince, uzun ve kurtçuğu andıran vücut şekilleriyle diğer bitkiyle beslenen akar gruplarından kolayca ayırt edilir. Gövdeleri çok küçük ve uzamış yapıdadır ve halka halka dizilmiş segmentlerden oluşur (Şekil 1). Besin alma organlarının bulunduğu gnathosoma bölgesi öne doğru uzamıştır ve beslenmeye uyumlu bir yapı gösterir. Dorsal ve ventral yüzeyde yer alan kalkanların şekli ve üzerindeki yapılar, cins ve türlerin ayırt edilmesinde önemli ipuçları sağlar. Ayrıca bacak uçlarındaki duyu yapıları (tarsal sensilla), vücut üzerindeki kıl dizilimleri (setalar) ve kütikula üzerindeki mikroskobik desenler, eriophyidlerin doğru tanılanmasında taksonomik açıdan kritik öneme sahiptir (Amrine & Stasny, 1994; de Lillo & Skoracka, 2010).

Şekil 1. Eriophyidae familyasının morfolojik tanısı (Science Photo Library, Media ID: 798412).

Tür Zenginliği

Dünya genelinde tanımlanmış eriophyoid tür sayısı yaklaşık 4.400 olup, bunların 3.200'den fazlası *Eriophyidae* familyası içinde yer almaktadır (Skoracka & Kuczyński, 2012). Ancak bu sayıların, grubun gerçek küresel çeşitliliğini tam olarak yansıtmadığı konusunda güçlü bir görüş birliği bulunmaktadır (Lindquist et al., 1996; Amrine et al., 2003).

Gerçek tür sayısının düşük görünmesinin başlıca nedenleri arasında eriophyidlerin dünya genelinde sınırlı ölçüde araştırılmış olması, özellikle tropik ve subtropik bölgelerde yetersiz örnekleme yapılması ve mikroskobik, aşırı sadeleşmiş vücut yapılarının morfolojiye dayalı tür ayrımını güçleştirmesi yer almaktadır (Navia et al., 2010; Krantz & Walter, 2009; de Lillo & Skoracka, 2010). Bu durum, birçok genetik olarak ayrışmış soyun tek bir takson altında değerlendirilmesine yol açmaktadır.

Ayrıca eriophyid türlerin büyük bir bölümünün yalnızca tek bir konukçu bitki türünde ve sınırlı popülasyonlar hâlinde bulunması, tespit ve örnekleme süreçlerini zorlaştırmaktadır (Skoracka et al., 2010). Moleküler çalışmalar, daha önce geniş konukçu spektrumlu tek tür olarak kabul edilen bazı taksonların gerçekte çoklu tür komplekslerinden oluştuğunu ortaya koymuştur (Carew et al., 2009; Skoracka & Kuczyński, 2012).

Konukçu bitki türü başına düşen ortalama eriophyoid tür sayısı yaklaşık 0,8 olarak hesaplanmakla birlikte, bu değerin dünya florasının büyük bölümünün henüz ayrıntılı olarak

incelenmemiş olması nedeniyle muhtemelen bir alt sınırı temsil ettiği düşünülmektedir (Skoracka et al., 2010; de Lillo et al., 2018).

KONUKÇU BİTKİ SEÇİCİLİĞİ VE KONUKÇU–AKAR ETKİLEŞİMLERİ

Eriophyidae'de Konukçu Özgüllüğünün Önemi

Eriophyidae familyası, bitki–akar etkileşimleri içinde bilinen en dar konukçu spektrumuna sahip gruplardan biridir. Küresel ölçekte eriophyoid türlerin yaklaşık %80'inin yalnızca tek bir bitki türünde, %95'inin ise tek bir bitki cinsi içinde sınırlı kaldığını ortaya koymaktadır (Skoracka et al., 2010). Bu yüksek konukçu seçiciliği, eriophyidlerin bitki dokularına son derece özgül uyumlar geliştirmesinin bir sonucudur ve özellikle gal oluşumu gibi karmaşık doku değişimlerinin ortaya çıkmasında belirleyici rol oynar. Konukçuya bu denli sıkı bağlılık, eriophyoid akarları bitki gelişimi, konukçuya adaptasyon süreçleri ve bitki etkileşimlerinin mekanizmalarını anlamak açısından önemli bir grup hâline getirmektedir.

Monofaji, Oligofaji ve Nadir Geniş Konukçu Kullanan Türler

Eriophyid akarların büyük çoğunluğu monofag olup yaşam döngülerini yalnızca tek bir konukçu bitki türü üzerinde tamamlar. Bu durum, özellikle *Aceria, Eriophyes, Cecidophyopsis* ve *Phyllocoptes* gibi türce zengin cinslerde belirgin şekilde görülmekte ve eriophyidlerin konukçu bitkiye yüksek düzeyde uyum sağladığını ortaya koymaktadır (Lindquist et al., 1996; Amrine & Stasny, 1994).

Bununla birlikte, sınırlı sayıda türün yakın bitki türleri arasında gelişebilen oligofag popülasyonlar oluşturabildiği bilinmektedir. Bu durum genellikle aynı bitki cinsi veya yakın akraba bitki grupları içinde gözlenmekte ve dar sınırlar içinde değişebildiğini göstermektedir (Skoracka et al., 2010; Skoracka & Kuczyński, 2012).

Gerçek anlamda geniş konukçu spektrumuna sahip eriophyid türler ise son derece nadirdir ve bu türlerin büyük kısmı, ayrıntılı moleküler çalışmalar sonucunda morfolojik olarak birbirine çok benzeyen ancak genetik olarak ayrışmış gizli tür kompleksleri olarak yeniden değerlendirilmiştir (Carew et al., 2009; Skoracka & Kuczyński, 2012).

Konukçu Seçimi ve Konukçu–Akar Etkileşimleri

Dünya genelinde tanımlanmış yaklaşık 4.400 eriophyoid tür bulunmasına karşın, bu sayının grubun gerçek küresel çeşitliliğini yansıtmadığı yaygın olarak kabul edilmektedir (Skoracka & Kuczyński, 2012; Lindquist et al., 1996). Sınırlı örnekleme, özellikle tropik bölgelerdeki araştırma eksikliği ve eriophyidlerin mikroskobik, oldukça sadeleşmiş vücut yapıları, morfolojiye dayalı tür ayrımını zorlaştırmakta ve birçok genetik olarak ayrışmış soyun tek takson altında değerlendirilmesine yol açmaktadır (Amrine et al., 2003; Navia et al., 2010; de Lillo & Skoracka, 2010). Türlerin büyük bölümünün yalnızca tek bir konukçu bitki türünde ve sınırlı populasyonlar hâlinde bulunması, bu durumu daha da belirginleştirmektedir (Skoracka et al., 2010). Moleküler çalışmalar, bazı taksonların gerçekte tür komplekslerinden oluştuğunu göstermiştir (Carew et al., 2009). Eriophyid akarlar, konukçu bitkilerde yalnızca beslenmeye bağlı doku kayıplarına değil; epidermal bronzlaşma ve pas benzeri belirtiler (*Aculops, Aculus*), erinoz oluşumu (Şekil 2) ve özellikle gal gelişimi gibi, bitki dokularının gelişimsel ve fizyolojik işleyişini değiştiren karmaşık etkileşimlere neden olur (Oldfield & Proeseler, 1996; 1996; Paponova et al., 2017; de Lillo et al., 2018).

Şekil 2. Eriophidlerin neden olduğu pas, erinoz, gal oluşumları

ERIOPHYIDLERİN BİTKİDE OLUŞTURDUĞU YAYGIN BELİRTİ TİPLERİ

Eriophyid akarlar, konukçu bitki dokularında oluşturdukları yapısal ve fizyolojik değişimlere göre belirgin belirtiler meydana getirir. Bu belirtiler, bitki dokusunun nasıl etkilendiğine bağlı olarak dört ana grupta toplanmaktadır. Bu sınıflandırma hem teşhis hem de zarar değerlendirmesi açısından temel bir çerçeve sunar.

Gal Oluşturan Eriophyidler

Gal oluşturan eriophyid akarlar, konukçu bitki dokularında hücre bölünmesini (hiperplazi) ve hücre büyümesini (hipertrofi) tetikleyerek normal dokudan farklılaşmış, yapısal ve işlevsel olarak özgün oluşumlar meydana getirir. Bu grubun en ayırt edici özelliği, konukçu bitkiye son derece dar bir bağlılık göstermeleridir; türlerin büyük çoğunluğu yalnızca tek bir bitki türünde gal oluşturabilmektedir (Skoracka et al., 2010; Skoracka & Kuczyński, 2012).

Gal gelişimi özellikle genç ve meristematik dokularda gerçekleşir ve hücre döngüsünün yeniden etkinleştirilmesi, doku polaritesinin bozulması ve yaprak yüzey kimliğinin değişmesiyle ilişkilidir. Beslenme sırasında eriophyid akarların tükürükleriyle bitki dokularına ilettiği kimyasal sinyaller, bitki içindeki fitohormon dengesini ve gelişim düzenleyici maddeleri etkileyerek dokuların normal gelişim seyrini değiştirir (Oldfield & Proeseler, 1996).

Gal dokusu içinde damar yapılarının yeniden düzenlenmesi sonucunda şeker ve aminoasit akışı artar; bu durum galin, akar için hem besince zengin hem de çevresel etkilere karşı korunaklı bir mikrohabitat hâline gelmesini sağlar (Jeppson et al., 1975; Childers et al., 2020).

Gal Tipleri, Morfolojik Çeşitlilik ve Gal Oluşturan Başlıca Cinsler

Gal oluşturan eriophyid akarlar, konukçu bitki grubuna bağlı olarak farklı morfolojik özellikler gösteren gal tipleri meydana getirir. Bu yapılar, bitki dokusunun hangi bölgesinin etkilendiğine ve dokusal yeniden düzenlenmenin derecesine bağlı olarak belirgin biçimde ayrışır. Literatürde eriophyid kaynaklı galler genellikle dört ana morfolojik grupta ele alınmaktadır (Amrine & Stasny, 1994; Lindquist et al., 1996; de Lillo et al., 2018).

Cepli galler, yaprak yüzeyinde kese ya da çukur şeklinde odacıklar hâlinde gelişir ve çoğunlukla yaprağın fotosentetik yüzeyini daraltır. Bu tip gallerin klasik örneği, ıhlamurda görülen *Eriophyes tiliae*'dir (Şekil 3). Tür, yaprak yüzeyinde kırmızımsı, içe doğru çökük cepli galler oluşturarak fotosentezi sınırlar ve erken yaprak yaşlanmasına neden olur. Benzer şekilde *Eriophyes pyri*, armut yapraklarında cepli gal oluşumuyla yaprak deformasyonları ve büyüme geriliği meydana getirir (Lindquist et al., 1996; Oldfield & Proeseler, 1996).

Şekil 3. Ihlamur yapraklarında *Eriophyes tiliae* zararı (Fotoğraf: Rosser1954 Roger Griffith, *Eriophyes tilae tilae* detail.JPG, Holger Krispile:Galle Lindengallmilbe Eriophyes tiliae.JPG Wikimedia Commons)

Çok odacıklı galler, damar dokusunun belirgin biçimde yeniden düzenlendiği ve yoğun hücre bölünmesiyle şekillenen karmaşık yapılardır. Bu gal tipi özellikle *Aceria* cinsi içinde yaygındır. *Aceria anthocoptes*, devedikeni üzerinde çok odacıklı galler oluşturarak sürgün gelişimini sınırlar (Şekil 4) ve bitkinin rekabet gücünü azaltır. Bu türde zarar, besin akışının gal dokusuna yönlendirilmesiyle bitkinin genel gelişim dengesinin bozulması şeklinde ortaya çıkar (Navia et al., 2010; de Lillo et al., 2018).

Şekil 4. Aceria anthocoptes'in meydana getirdiği çok odacıklı galler

Tomurcuk galler, tomurcukların anormal büyümesi ve sürgün deformasyonlarıyla karakterizedir ve çoğunlukla *Cecidophyopsis* cinsine ait türler tarafından oluşturulur. Kuş üzümünde yaygın olarak görülen *Cecidophyopsis ribis*, tomurcuk içini tamamen dolduran büyük böbrek şeklindeki gallerle tomurcuğun normal gelişimini engeller. Bu durum çiçeklenmenin azalmasına, meyve tutumunun düşmesine ve uzun vadede bitkinin zayıflamasına yol açar (Lindquist et al., 1996; Navia et al., 2010). Tomurcuk gallerine en önemli örneklerden biri de fındıkta görülen *Phytoptus avellanae*'dir (Kaya, et. al., 2023) ve tomurcuklarda kozalak benzeri gal yapıları oluşturmaktadır (Şekil 5).

Şekil 5. *Phytoptus avellanae* fındık kozalak akarının oluşturduğu galler ve gal oluşturan bireyler (Fotoğraf: Gilles San Martin (Wikimedia Commons), File:Phytoptus avellanae.jpg)(

Fotoğraf: Stephen James McWilliam (Wikimedia Commons), File:Phytoptus avellanae (Liverpool, UK).jpg

Damar galleri (damar kalınlaşmaları); yaprak ana veya yan damarları boyunca şişkinlik ve kalınlaşma şeklinde ortaya çıkar yaprak mimarisini doğrudan etkiler. Kavakta görülen *Aceria parapopuli*, damar dokuları boyunca oluşturduğu gallerle yaprak formunu bozar (Şekil) ve büyüme performansını düşürür. Bu tip gallerde damar dokusunun yeniden düzenlenmesi, gal içindeki besin birikimini artıran temel mekanizmadır (Amrine & Stasny, 1994; de Lillo et al., 2018).

Şekil 6. *Aceria parapopuli* nin oluşturduğıu galleri

Gal Oluşturan Türlerin Tarımsal Önemi

Gal oluşturan eriophyid akarlar, tarımsal sistemlerde hem doğrudan hem de dolaylı etkileri nedeniyle önemli zararlılar arasında yer alır. Yaprak, sürgün ve tomurcuk dokularında meydana gelen yapısal deformasyonlar fotosentez kapasitesini azaltır, bitkinin büyüme dengesini bozar ve uzun vadede belirgin verim kayıplarına yol açar. Bu etkiler özellikle odunsu kültür bitkilerinde daha belirgin hâle gelmektedir.

Türkiye koşullarında gal oluşturan eriophyidlere ait en dikkat çekici örneklerden biri, fındıkta yaygın olarak görülen fındık kozalak akarı *Phytoptus avellanae*'dir. Bu tür, tomurcuklarda kozalak benzeri galler oluşturarak sürgün gelişimini engeller, çiçek tomurcuğu oluşumunu sınırlar ve doğrudan verim kaybına neden olur. Oluşturduğu yapılar, tomurcuk galinin tipik bir örneği olup gal oluşturan eriophyidler grubunda değerlendirilir (Lindquist et al., 1996; Navia et al., 2010).

Benzer şekilde, Türkiye'de park ve süs bitkilerinde yaygın olan ıhlamur ağaçlarında *Eriophyes tiliae*, yapraklarda ceplik galler oluşturarak yaprak yüzeyinin işlevsel alanını daraltır ve erken yaprak yaşlanmasına yol açar. Kavakta görülen *Aceria parapopuli* ise yaprak damarları boyunca gelişen gallerle yaprak mimarisini bozarak büyüme performansını düşürür. Bu türlerin ortak özelliği, zararlarının belirli konukçu bitkilerde yoğunlaşması ve bitkinin fizyolojik kapasitesini kademeli olarak azaltmasıdır (Lindquist et al., 1996; de Lillo et al., 2018).

Türkiye tarımı açısından en önemli örneklerden biri de fındıkta görülen *Phytoptus avellanae*'dir (Kaya, et. al, 2023). Bu tür, tomurcuklarda kozalak benzeri gal yapıları oluşturarak sürgün gelişimini sınırlar, çiçek tomurcuğu oluşumunu azaltır ve doğrudan verim kaybına yol açar.

Gal oluşturan eriophyidlerin tarımsal önemi yalnızca doğrudan doku deformasyonlarıyla sınırlı değildir. Bazı türler aynı zamanda bitki virüslerinin taşınmasında rol oynayarak dolaylı zarar oluşturur. Bu durum, gal oluşumunun yanı sıra epidemiyolojik risklerin de dikkate alınmasını gerektirir. Bu nedenle tarımsal üretimde erken teşhis, düzenli izleme ve doğru tür tanımlaması

açısından özel dikkat gerektiren bir grup olarak değerlendirilmektedir (Smith et al., 2010; de Lillo et al., 2018).

Erinoz Oluşturan Eriophyidler

Erinozun Tanımı ve Genel Özellikleri

Erinoz, eriophyid akarların konukçu bitki yapraklarında oluşturduğu, çoğunlukla yaprak alt yüzeyinde gelişen yoğun ve keçemsi tüylenme tabakası ile karakterize bir belirti tipidir. Bu yapı, gerçek bir gal oluşumundan farklı olarak kapalı bir doku yapısı içermez; ancak bitki dokusunda belirgin anatomik ve fizyolojik değişimlere yol açar. Erinoz oluşumu, özellikle yaprak epidermisi ve mezofil dokusunun yeniden düzenlenmesiyle ilişkilidir (Lindquist et al., 1996; de Lillo et al., 2018).

Erinoz Oluşum Mekanizması, Morfolojik ve Anatomik Özellikleri

Erinoz oluşumu, eriophyid akarların beslenme sırasında bitki dokularına ilettiği kimyasal sinyallerin, bitki içindeki fitohormon dengesini ve aynı zamanda bitki içindeki gelişim düzenleyici maddeleri etkilemesiyle başlar. Bu etki sonucunda trikom gelişimi uyarılır ve normalden çok daha yoğun, sık ve düzensiz bir tüylenme tabakası ortaya çıkar. Erinoz tabakası genellikle yaprak alt yüzeyinde gelişir ve yaprağın doğal yüzey mimarisini belirgin biçimde değiştirir (Oldfield & Proeseler, 1996).

Erinozlu yapraklarda epidermal hücrelerde kalınlaşma, trikom yoğunluğunda artış ve mezofil dokusunda düzensiz hücre dizilimi gözlenir. Erinoz tabakası, yaprak yüzeyinde hava akışını ve ışık geçirgenliğini azaltarak fotosentez kapasitesinin düşmesine neden olur. Ayrıca bu yapı, yaprak yüzeyinde nem tutulumunu artırarak mikroklimatik koşulları değiştirir ve yaprak dokusunun fizyolojik dengesini bozar (Lindquist et al., 1996; Childers et al., 2020).

Erinoz Oluşturan Başlıca Cins ve Türler

Erinoz oluşturan eriophyid türler belirli cinslerde yoğunlaşmaktadır. *Aceria (Eriophyes) tiliae,* ıhlamur ağaçlarında yaygın olarak görülür ve yaprak alt yüzeyinde yoğun erinoz tabakası oluşturarak yaprakların solunum ve fotosentez kapasitesini belirgin biçimde azaltır. *Aceria oleae,* zeytinde erinoz benzeri yoğun tüylenme ve yaprak deformasyonlarına yol açarak ağacın fizyolojik dengesini ve verim potansiyelini düşürür. *Colomerus vitis,* asma yapraklarında erinozun en iyi bilinen örneklerinden biridir; bu tür hem yapraklarda erinoz oluşumuna hem de tomurcuk gelişiminde bozulmalara neden olur (Şekil 7) ve salkım oluşumunu olumsuz etkiler (Lindquist et al., 1996; Oldfield & Proeseler, 1996; de Lillo et al., 2018).

Şekil 7. *Colomerus vitis'in* meydana getirdiği erinoz zararı (https://www.dreamstime.com/photos-images/colomerus-vitis.html)

Erinozun Bitki Fizyolojisi ve Verim Üzerine Etkileri

Erinoz oluşumu, bitkide genellikle doğrudan doku kaybı yaratmaz; ancak fotosentez kapasitesinin azalması, gaz alışverişinin kısıtlanması ve yaprak dokusunun erken yaşlanması

gibi kümülatif etkilerle verim düşüşüne neden olur. Uzun süreli ve yoğun erinoz varlığı, bitkinin büyüme dengesini bozar ve özellikle çok yıllık bitkilerde yıllar içinde belirgin performans kayıplarına yol açar (de Lillo et al., 2018; Childers et al., 2020).

Erinoz oluşturan eriophyidler, özellikle bağ, zeytinlik ve süs bitkileri gibi sistemlerde ekonomik açıdan önem taşır. Belirtiler çoğu zaman gözden kaçabildiği için zarar geç fark edilir ve bu durum kayıpların artmasına neden olur. Bu nedenle erinoz belirtilerinin doğru tanımlanması, türün doğru teşhisi ve popülasyonların izlenmesi, entegre mücadele stratejilerinin planlanmasında kritik rol oynar (Oldfield & Proeseler, 1996; de Lillo et al., 2018).

Pas / Bronzlaşma Oluşturan Eriophyidler

Genel Tanım ve Zararın Niteliği

Pas veya bronzlaşma oluşturan eriophyid akarlar, konukçu bitkilerin özellikle yaprak epidermisi üzerinde yüzeysel beslenme yoluyla hücresel bütünlüğü bozan türlerden oluşur. Bu grupta gal veya erinoz gibi belirgin doku proliferasyonları yerine, epidermal hücrelerin çökmesi, klorofil kaybı ve kütikula yapısının bozulması ön plandadır. Sonuç olarak yapraklarda pas rengi, bronz tonlar veya matlaşma şeklinde görsel belirtiler ortaya çıkar (Lindquist et al., 1996; de Lillo et al., 2018).

Bu zarar tipi genellikle bitkinin fotosentetik kapasitesinde azalma, su dengesinde bozulma ve uzun vadede büyüme geriliği ile ilişkilidir. Pas ve bronzlaşma belirtileri, özellikle yüksek popülasyon yoğunluklarında bitkinin genel fizyolojik performansını belirgin biçimde düşürmektedir.

Zarar Mekanizması

Pas oluşturan eriophyidler beslenme sırasında epidermal hücrelerin içeriğini emerek hücre duvarlarında mikroskobik hasara neden olur. Bu süreçte:

- Epidermal hücrelerde çökme ve nekroz benzeri yapısal bozulmalar,
- Kloroplastların işlev kaybı ve klorofil degradasyonu,
- Kutikula bütünlüğünün zayıflaması ve yüzeyin değişmesi gözlenir. Bu fizyolojik bozulmalar yaprak yüzeyinde pas veya bronz renkli bir görünüm oluşturur. Zarar genellikle ilerleyici nitelikte olup, yaprağın tamamına yayılabilir (Jeppson et al., 1975; Childers et al., 2020).

Başlıca Türler ve Konukçu Bitkiler

Pas / bronzlaşma oluşturan eriophyidlerin önemli bir bölümü *Aculops, Aceria* ve *Phyllocoptes* cinslerinde yoğunlaşmaktadır.

Aculops lycopersici: Domateste görülen en önemli pas akarlarından biridir. Yapraklarda hızlı bronzlaşma, yaprak kıvrılması, gövde ve meyvelerde matlaşma oluşturur (Şekil 8). Yüksek yoğunluklarda bitkide genel çöküşe kadar ilerleyebilen zarar meydana getirir (Jeppson et al., 1975; Lindquist et al., 1996).

Şekil 8. *Aculops lycopersici*. Domates yaprağında bronzlaşma oluşturan ergin birey (Fotoğraf: Gilles San Martin (Wikimedia Commons), CC BY-SA 4.0.

Aculus schlechtendali: Elmada yaprak üst yüzeyinde pas renkli görünüm ve matlaşma oluşturur (Şekil 9) Fotosentez kapasitesinin azalmasına bağlı olarak meyve iriliğinde düşüş ve yıllık sürgün gelişiminde zayıflama görülür (Childers et al., 2020; de Lillo et al., 2018).

Şekil 9. *Aculus schlechtendali*. Ergin bireyler, elma yaprağında ve meyvesinde bronzlaşma ve pas benzeri zarar belirtileri. Fotoğraf: (https://treefruit.wsu.edu/crop-protection/opm/apple-rust-mite/).

Phyllocoptes gracilis: Bazı odunsu bitkilerde yaprak yüzeyinde bronzlaşma ve epidermal bozulmalara neden olur. Zarar çoğunlukla estetik ve fizyolojik kalite kaybı şeklinde ortaya çıkar (Lindquist et al., 1996).

Türkiye'de bağ, elma ve sebze alanlarında bronzlaşma belirtileriyle ilişkili eriophyid türlerin varlığı bildirilmiş; özellikle *Aculus ve Aceria* türlerinin yaygın olduğu belirtilmiştir (Çobanoğlu, 2002; Akyazı & Ecevit, 2008).

Tarımsal Önemi

Pas ve bronzlaşma oluşturan eriophyidler, gal oluşturan türlere kıyasla daha az dikkat çekici belirtiler oluştursa da kümülatif ve süreklilik gösteren zararları nedeniyle tarımsal açıdan son derece önemlidir. Fotosentez kaybı, yaprak erken yaşlanması ve ürün kalitesinde düşüş bu grubun başlıca etkileridir.

Özellikle sebze ve meyve üretiminde bronzlaşma belirtileri, pazar değerini doğrudan düşürmekte; yüksek popülasyonlarda ise bitkinin genel gelişimini baskılamaktadır. Bu nedenle pas oluşturan eriophyidler, entegre mücadele programlarında erken teşhis ve düzenli izleme gerektiren bir zarar grubunu temsil eder (de Lillo et al., 2018).

GAL OLUŞUM MEKANİZMALARI

Eriophyidae türlerinin gal oluşturma kapasitesi, bitki–akar etkileşimleri içinde en karmaşık gelişimsel düzenleme örneklerinden birini oluşturur. Gal oluşumu; akarların beslenme sırasında

bitki dokusuna aktardığı tükürük salgılarıyla başlar ve bitki içindeki fitohormon ile gelişim düzenleyici maddeleri etkilediği bilinen sinyallerin yönlendirilmesiyle ilerler. Bu süreçte hücre döngüsü yeniden düzenlenir, damar dokusu gal yapısına doğru yönlendirilir ve savunma yanıtları gal bölgesinde yerel olarak baskılanır (Lindquist et al., 1996; de Lillo et al., 2018; Paponova et al., 2017).

Gal gelişimi çoğunlukla kışlayan dişi akarların genç ve meristematik dokularda beslenmeye başlamasıyla tetiklenir. Tükürük salgıları, bitki hücrelerinde fizyolojik dengeyi bozarak yoğun hücre bölünmesini başlatır ve bu etki akar beslenmesi sürdüğü sürece devam eder. Beslenmenin kesilmesiyle birlikte gal gelişiminin durması, sürecin doğrudan akar varlığına bağlı olduğunu göstermektedir (Oldfield & Proeseler, 1996; Paponova et al., 2017).

Bu aşamada özellikle auksin ve sitokinin dengesindeki değişimler belirleyici rol oynar. Auksin dağılımındaki bozulmalar hücre polaritesinin kaybına ve yönsüz büyümeye yol açarken, sitokininler yoğun hücre bölünmesini ve çok odacıklı gal yapılarının oluşumunu destekler. Aynı zamanda jasmonat ve salisilik asit temelli savunma yanıtlarının yerel olarak baskılanması, gal dokusunun stabil biçimde gelişmesini kolaylaştırır (Paponova et al., 2017; Childers et al., 2020; Desnitskiy et al., 2023).

Gal olgunlaştıkça bitki dokusunda belirgin anatomik ve histolojik değişimler ortaya çıkar. Yoğun hücre çoğalması, parankim dokusunun genişlemesi ve damar dokusunun gal içine doğru yeniden yönlendirilmesi, galin besince zengin bir yapı hâline gelmesini sağlar. Epidermal tabakanın kalınlaşması ve antosiyanin gibi pigmentlerin birikimi ise gal dokusuna mekanik ve fizyolojik koruma kazandırır. Özellikle *Eriophyes tiliae* tarafından oluşturulan gallerde görülen kırmızı renklenme, bu koruyucu sürecin tipik bir göstergesidir (Lindquist et al., 1996; de Lillo et al., 2018; Desnitskiy et al., 2023).

SONUÇ

Eriophyidae familyası, dar konukçu seçiciliği ve bitki dokularında oluşturduğu gal, erinoz ve pas benzeri belirtilerle bitki–akar etkileşimleri içinde özel bir konuma sahiptir. Bu akarların zararları, yalnızca beslenmeye bağlı doku kaybı değil; bitkinin gelişimsel ve fizyolojik süreçlerinin yeniden yönlendirilmesiyle ortaya çıkan kalıcı etkiler şeklinde gerçekleşmektedir. Mevcut veriler, eriophyid çeşitliliğinin dünya genelinde ve özellikle Türkiye'de büyük ölçüde eksik tanımlandığını göstermektedir. Bu nedenle, doğru tür teşhisi, erken tanı ve biyoloji temelli entegre mücadele yaklaşımlarının geliştirilmesi kritik öneme sahiptir. Gelecekte yapılacak çalışmaların, gal oluşum mekanizmaları ve konukçu–akar etkileşimlerinin moleküler temellerine odaklanması hem temel hem de uygulamalı akaroloji açısından önemli katkılar sağlayacaktır.

KAYNAKLAR

Amrine, J. W., & Stasny, T. A. (1994). *Catalog of the Eriophyoidea (Acarina: Prostigmata) of the world*. Indira Publishing House.

Amrine, J. W., Stasny, T. A., & Flechtmann, C. H. W. (2003). *Revised keys to world genera of Eriophyoidea (Acari: Prostigmata)*. Indira Publishing House.

Akyazı, R., & Ecevit, O. (2008). Eriophyoid mites (Acari: Eriophyoidea) on hazelnut in Turkey. *International Journal of Acarology, 34*(1), 1–6.

Bayram, S., & Çobanoğlu, S. (2013). Türkiye eriophyoid akar faunası üzerine değerlendirmeler. *Türkiye Entomoloji Dergisi, 37*(2), 213–224.

Carew, M. E., Marshall, S. E., Hoffmann, A. A., & Miles, M. (2009). A combination of molecular and morphological approaches resolves cryptic species within the *Aceria* complex. *Molecular Ecology, 18*(16), 3246–3260.

Childers, C. C., Ueckermann, E. A., & De Moraes, G. J. (2020). *Acarology: mites and human welfare*. Springer.

Çobanoğlu, S. (2002). Türkiye eriophyoid akarları üzerine ilk kayıtlar. *Türkiye Entomoloji Dergisi, 26*(1), 45–56.

de Lillo, E., and Skoracka, A. (2010). What's "cool"on eriophyoid mites? *Exp. Appl. Acarol.* 51, 3–30. doi: 10.1007/s10493-009-9297-4

de Lillo, E., Pozzebon, A., Valenzano, D., & Duso, C. (2018). An intimate relationship between eriophyoid mites and their host plants. *Experimental and Applied Acarology, 76*(2), 181–209.

Denizhan, E., Çobanoğlu, S., & Çakmak, İ. (2022). Five new records of eriophyid mites (Acari: Eriophyoidea) from herbaceous plants and fruit trees in Van province, Turkey. Journal of Agricultural Sciences, 28(1), 133-138. https://doi.org/10.15832/ankutbd.833925

Desnitskiy, A. G., Chetverikov, P. E., Ivanova, L. A., Kuzmin, I. V., Ozman-Sullivan, S. K., & Sukhareva, S. I. (2023). Molecular aspects of gall formation induced by mites and insects. *Life, 13*(6), 1347.

Jeppson, L. R., Keifer, H. H., & Baker, E. W. (1975). *Mites injurious to economic plants*. University of California Press.

Kaya, D., Öztemiz, S., & Ciner, İ. (2023). Düzce İli Fındık Bahçelerinde Fındık Kozalak Akar Türleri ve Bulaşma Oranının Belirlenmesi. Duzce University Journal of Science and Technology, 11(2), 859-867.

Klimov, P. B., Tolstikov, A. V., & Skoracka, A. (2022). Phylogenomics of eriophyoid mites reveals extreme host specialization. *Molecular Phylogenetics and Evolution, 168*, 107368.

Krantz, G. W., & Walter, D. E. (2009). A manual of acarology. 3rd edn. Texas Tech University Press, Lubbock.

Lindquist, E. E., Sabelis, M. W., & Bruin, J. (Eds.). (1996). *Eriophyoid mites: Their biology, natural enemies and control*. Elsevier.

Navia, D., de Moraes, G. J., Roderick, G., & Navajas, M. (2010). The invasive potential of eriophyoid mites and their importance as agricultural pests. *Experimental and Applied Acarology, 51*(1–3), 225–255.

Oldfield, G. N., & Proeseler, G. (1996). Eriophyoid mites as vectors of plant pathogens. In E. E. Lindquist et al. (Eds.), *Eriophyoid mites: Their biology, natural enemies and control* (pp. 259–275). Elsevier.

Paponova, S. S., Tolstikov, A. V., & Desnitskiy, A. G. (2017). Histological and physiological features of gall formation induced by eriophyoid mites. *Biology Bulletin, 44*(7), 781–789.

Skoracka, A., & Kuczyński, L. (2012). Host specialization and cryptic diversity in eriophyoid mites. *Experimental and Applied Acarology, 57*(1), 1–19

Skoracka, A., Smith, L., Oldfield, G., Cristofaro, M., & Amrine, J. W. (2010). Host-plant specificity and specialization in eriophyoid mites. *Annual Review of Entomology, 55*, 417–439.

Smith, J. T., Jones, A. T., & McGavin, W. J. (2010). Eriophyid mites as vectors of plant viruses. *Virus Research, 151*(1), 1–15.

DRIED FRUIT MITE *Carpoglyphus lactis*: BIOLOGY, FOOD CONTAMINATION AND PROSPECTS FOR SUSTAINABLE CONTROL

KURU MEYVE AKARI *Carpoglyphus lactis*: BİYOLOJİ, GIDA KONTAMİNASYONU VE SÜRDÜRÜLEBİLİR MÜCADELE POTANSİYELLERİ

Nihal KILIÇ

Tekirdağ Namık Kemal Üniversitesi, Ziraat Fakültesi, Bitki Koruma Bölümü, Tekirdağ, Türkiye

ORCID ID: https://orcid.org/0000-0002-7538-7444

Eylül Duru YÜCEL

Tekirdağ Namık Kemal Üniversitesi, Ziraat Fakültesi, Bitki Koruma Bölümü, Tekirdağ, Türkiye

ORCID ID: https://orcid.org/ 0009-0007-7343-3287

ÖZET

Carpoglyphus lactis (Astigmata: Carpoglyphidae), şekerce zengin depolanmış ürünlerde hızla çoğalarak kalite kaybına ve gıda güvenliği sorunlarına yol açan, yaygın olarak "kuru meyve akarı" olarak bilinen önemli bir zararlıdır. Türün kuru incir, kayısı, üzüm ve hurma gibi geleneksel kuru meyvelere ek olarak reçel, bal, polen, arı ekmeği, pekmez ve sirke gibi fungus ve maya açısından zengin ortamlarda da bulunabilmesi, onun fermente ürünlere de kolaylıkla uyum sağlayabilen bir zararlı olduğunu göstermektedir. *C. lactis* ürünlerde sindirim artıkları, salgıları ve ölü bireylerin kalıntılarıyla fungus gelişimini hızlandırarak istenmeyen tat ve koku oluşumuna, renk kararmasına ve doku bozulmasına neden olur. Özellikle kuru kayısılarda üründe yumuşama ve yapışkanlık ürünün ticari değerini belirgin şekilde düşürmektedir.

Yapılan araştırmalarda kuru incirlerin bazı örneklerinde akarın kilogram başına 10.000'i aşan yoğunluklara ulaşabildiğini bildirilmektedir. Bu durum türün depolama sürecinde sürekli bir risk oluşturduğunu ve uygun koşullar altında çok hızlı popülasyon artışı sergileyebildiğini göstermektedir. Öte yandan bazı kimyasal fumigantların yasaklanması, direnç sorunları ve tüketicilerin kalıntı konusundaki hassasiyeti, alternatif mücadele yöntemlerinin önemini artırmıştır.

Son yıllarda yapılan çalışmalar, *C. lactis*'in oksijen ve nem düzeylerine duyarlı olduğunu ortaya koymuş; ozon gazı, ferrik oksit, kalsiyum klorür ve silika jel gibi fiziksel ajanların paketli kuru kayısıda etkili kontrol sağladığı belirlenmiştir. Ozon kısa sürede yüksek ölüm oranı oluştururken, ferrik oksit oksijen seviyesini düşürerek etkili olmaktadır. Bunun yanında, yerli diatomlu toprak uygulamalarının akarın dış kutikula tabakasını aşındırarak hızlı su kaybına yol açtığı ve farklı sıcaklık koşullarında popülasyon gelişimini başarıyla baskıladığı bildirilmiştir.

Bu çalışma, *C. lactis*'in biyolojisini, ekolojisini, bazı organizmalarla etkileşimini ve çevre dostu alternatif mücadele yöntemlerini bütüncül bir yaklaşımla ele alarak, depolama ekosistemlerinde

sürdürülebilir ve güvenli yönetim stratejileri geliştirmek için güncel bir bilimsel çerçeve sunmayı amaçlamaktadır.

Anahtar Kelimeler: *Carpoglyphus lactis,* depo akarları, gıda kontaminasyonu, alternatif mücadele; diatom toprağı.

ABSTRACT

Carpoglyphus lactis (Astigmata: Carpoglyphidae), commonly known as the “dried fruit mite,” is an important pest that rapidly proliferates in sugar-rich stored products, causing quality degradation and food safety concerns. The presence of this species not only in traditional dried fruits such as figs, apricots, grapes, and dates but also in fungus- and yeast-rich substrates including jam, honey, pollen, bee bread, molasses, and vinegar demonstrates its strong ability to adapt to fermented food environments. *C. lactis* accelerates fungal development through its digestive residues, secretions, and the accumulation of dead individuals, leading to off-flavors, discoloration, and textural deterioration. In dried apricots in particular, product softening and increased stickiness markedly reduce the commercial value of the commodity.

Studies have reported that the mite can reach densities exceeding 10,000 individuals per kilogram in some dried fig samples. This indicates that the species poses a continuous risk during storage and is capable of very rapid population growth under favorable conditions. In addition, the restriction of certain chemical fumigants, resistance problems, and consumer sensitivity to chemical residues have further increased the importance of alternative control methods.

Recent studies have shown that *C. lactis* is sensitive to oxygen and humidity levels, and physical agents such as ozone gas, ferric oxide, calcium chloride, and silica gel have been demonstrated to provide effective control in packaged dried apricots. While ozone induces rapid mortality, ferric oxide is effective by reducing oxygen concentration. Furthermore, the application of locally produced diatomaceous earth has been reported to abrade the mite’s cuticular layer, causing rapid water loss and successfully suppressing population growth under various temperature conditions.

This review aims to provide an up-to-date scientific framework by examining the biology, ecology, interactions with certain microorganisms, and environmentally friendly alternative control methods of *C. lactis*, thereby contributing to the development of sustainable and safe management strategies in stored-product ecosystems.

Keywords: *Carpoglyphus lactis,* stored-product mites, food contamination, alternative control, diatomaceous earth.

Giriş

Kuru meyve akarı *Carpoglyphus lactis* (L.) (Acari: Carpoglyphidae), gıda depolama ekosistemlerinde yaygın olarak bulunan ve özellikle kuru incir, kayısı, üzüm, hurma ve pekmez gibi yüksek şeker içerikli ürünlerde hızla çoğalabilen kozmopolit bir türdür. Akarın bu ürünlerde oluşturduğu zarar, yalnızca fiziksel tüketimle sınırlı olmayıp; salgıladığı enzimler, dışkı partikülleri ve kutikula kalıntıları aracılığıyla ürünün kimyasal ve mikrobiyolojik yapısında bozulmalara yol açarak ekonomik kayıplara neden olmaktadır (Hughes, 1976, Hubert et.al, 2015). Bu bozulmalar, meyve yüzeyinde yumuşama, renk değişimi, yapışkanlık artışı ve fermente kokular şeklinde duyusal kalite kayıplarıyla kendini gösterir.

Türkiye'de yapılan kapsamlı bir çalışmada, kuru incir örneklerinin %94,3'ünde akar bulaşıklığının bulunduğu ve *C. lactis*'in bazı partilerde kilogram başına 10.488 bireye kadar ulaşabildiği rapor edilmiştir (Dizlek et al., 2019). Bu bulgular, türün depolama aşamasında hızlı popülasyon artışı gösterdiğini ve gıda güvenliğini tehdit eden önemli bir kontaminasyon ajanı olduğunu doğrulamaktadır. Türün insan sağlığı açısından da önemi büyüktür; akar parçacıkları ve dışkıları solunum ve gıda kaynaklı alerjenler arasında yer almakta, hassas bireylerde dermatit ve solunum sorunlarına yol açabilmektedir (Colloff, 2009).

C. lactis'in biyolojisi ve ekolojisi, yüksek nem ve şeker içeriği bulunan mikrohabitatlara güçlü bir uyum göstermesiyle karakterizedir. Türün gelişim süresi sıcaklıkla birlikte kısalmakta ve özellikle daha sıcak–daha nemli koşullarda popülasyon artış potansiyeli belirgin biçimde yükselmektedir; örneğin kuru kayısı üzerinde yürütülen yaşam çizelgesi verileri, 28 °C ve %80 bağıl nemde içsel artış hızının en yüksek düzeye çıktığını ve jenerasyon süresinin kısaldığını göstermiştir (Güldalı & Çobanoğlu, 2010). Ayrıca birçok kuru meyvede doğal olarak bulunan maya ve funguslarla etkileşim hâlinde olması, mikrobiyal enzim ve organik asit üretimiyle besin yüzeyinin daha erişilebilir hâle gelmesi üzerinden akarın beslenme verimliliğini artırarak popülasyonun hızla yükselmesine katkı sağlayabilmektedir (Hubert et al., 2021). Bu nedenle *C. lactis*, gıda maddelerinde kimyasal/mikrobiyal bozunma süreçlerinin hem tetikleyicisi hem de hızlandırıcısı olarak değerlendirilebilir.

Depo akarlarının kimyasal fumigantlarla kontrolü geleneksel olarak fosfin, kükürt dioksit ve metil bromür gibi maddelere dayanıyordu; ancak fosfine karşı direnç gelişimi, metil bromürün Montreal Protokolü kapsamında yasaklanması ve gıda güvenliğine ilişkin yasal sınırların sıkılaşması, bu türlere karşı alternatif mücadele yöntemlerinin geliştirilmesini zorunlu kılmıştır (Subramanyam & Roesli, 2000). Güncel araştırmalar, inert tozlar, uçucu yağlar, sıcaklık–nem yönetimi ve atmosfer manipülasyonu gibi kimyasal olmayan uygulamaların *C. lactis* üzerinde yüksek etkinlik sağlayabildiğini göstermiştir.

Bu derlemenin amacı, *C. lactis*'in biyolojisini, ekolojisini, gıda kontaminasyonundaki rolünü ve sürdürülebilir mücadele potansiyellerini güncel bilimsel veriler ışığında değerlendirmek; ayrıca mevcut literatürdeki boşlukları belirleyerek gelecekteki araştırmalara yön verecek kapsamlı bir çerçeve sunmaktır. Depolama zararlıları arasında nispeten ihmal edilmiş olan bu türün, küresel gıda ticaretinde artan ekonomik ve sağlık riskleri nedeniyle ayrıntılı biçimde incelenmesi artık kaçınılmaz görünmektedir.

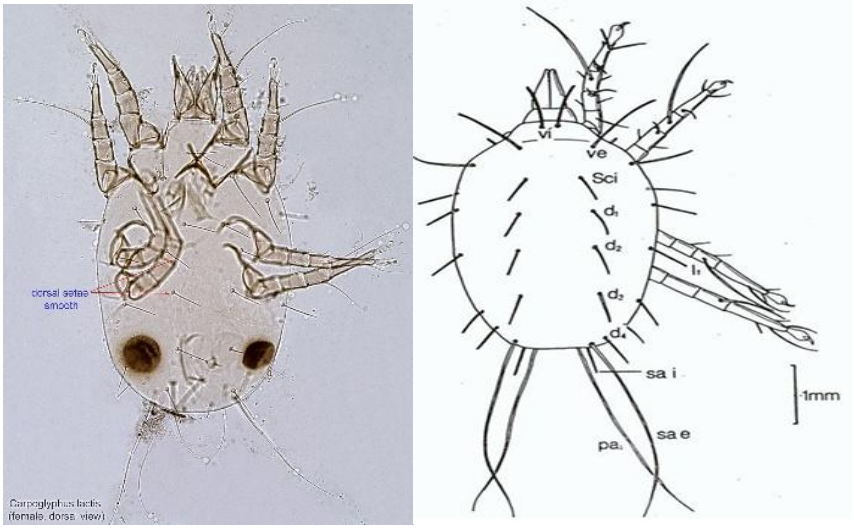
Taksonomi ve Tanımlama

Şube (Phylum): Arthropoda
Sınıf (Classis): Arachnida
Alt sınıf (Subclassis): Acariformes
Takım (Ordo): Sarcoptiformes
Üst aile / Üst grup (Supercohort): Astigmata
Aile (Familia): Carpoglyphidae
Cins (Genus): *Carpoglyphus*
Tür (Species): *Carpoglyphus lactis* (Linnaeus, 1758)

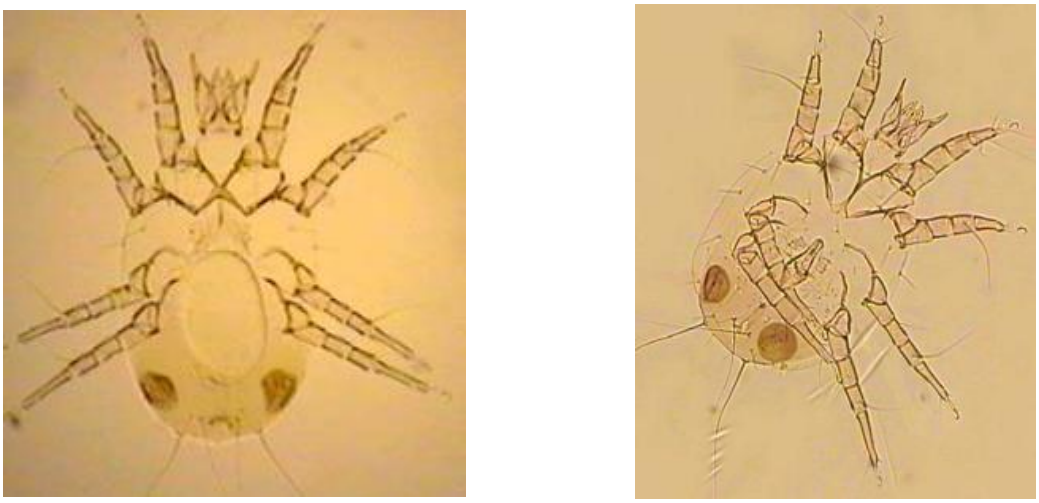
Kuru meyve akarı olarak bilinen *Carpoglyphus lactis*, Arthropoda şubesinin Arachnida sınıfında, Acari alt sınıfının Astigmata üst grubunda yer alan Acaridae familyasına bağlıdır. Familya içinde *Carpoglyphus* cinsi, gıda ve depolama ürünleriyle ilişkili türlerin yoğunlaştığı küçük fakat ekolojik açıdan önemli bir gruptur. *C. lactis*, bu cins içinde en yaygın ve ekonomik önemi en yüksek tür olarak tanımlanmaktadır (Krantz & Walter, 2009).

Morfolojik Özellikleri

C. lactis, yumuşak ve ince kutikulalı vücut yapısıyla diğer birçok depolama akarıyla benzerlik göstermekle birlikte, morfolojik açıdan ayırt edici bazı özelliklere sahiptir. Ergin bireyler oval formda olup yaklaşık 300–450 µm uzunluğundadır; (Şekil 1, Şekil 2) vücutları açık krem renginde ve yarı şeffaftır. Larval evre üç çift bacak taşırken, protonimf ve tritonimf dönemlerinde dört çift bacağa sahip olur. Bu evre değişimleri, tür teşhisinde önemli mikroskobik ipuçları sunar (Hughes, 1976). Kutikulası oldukça ince bir lipid tabakasıyla kaplıdır; bu özellik *C. lactis*'in inert tozlara ve uçucu yağlara karşı yüksek duyarlılığını açıklayan temel anatomik faktörlerden biridir (Krantz, 2009).



Şekil 1. *Carpoglyphus lactis (Vladivostok popülasyonu) dişisinin dorsal görünümü ve* vücut setalarının görünüşü (Hughes 1976). *Fotoğraf: Pavel Klimov, Bee Mite ID – USDA, public domain.* https://commons.wikimedia.org/wiki/Category:Carpoglyphus_lactis#/media/File:6-Carpoglyphus_lactis_Vladivostok_female_dors_BF20.jpg,



Şekil 2. *Carpoglyphus lactis* (Lineé1758) sırasıyla dişi ve erkek bireylerinin genel görünüşü (x20) (güldalı, 2007)

C. lactis'in ince, düşük sklerotize kutikulaya sahip olması, onu hem çevresel streslere hem de fiziksel ve kimyasal mücadele ajanlarına karşı oldukça duyarlı hâle getirir. Lipit tabakasının ince oluşu, inert tozların (diatom toprağı, kaolin, zeolit) kutikula yüzeyindeki koruyucu yağ tabakasını hızla aşındırmasına izin verir; bu da diatom toprağı (DE)'nın bu türde neden çok hızlı mortalite oluşturduğunu açıklar. Aynı zamanda uçucu yağ bileşenlerinin (ör. fenolikler,

terpenoidler) kutikula lipitlerini çözerek membran bütünlüğünü bozma etkisi, *C. lactis*'te temas toksisitesinin yüksek olmasının ana nedenlerinden biridir (Isman, 2006).

Kutikulanın su tutma kapasitesinin düşük olması, akarın nem kaybına karşı sınırlı bir toleransa sahip olmasına yol açar. Bu nedenle %60'ın altındaki bağıl nemde ölüm oranları hızla artmakta, DE gibi desikantlarla birlikte uygulandığında sinerjik kontrol etkisi ortaya çıkmaktadır (Arlian, 1975; Fields & Korunic, 2000).

Biyolojik Özellikleri ve Meydana Getirdiği Zararlar

Biyoloji ve Yaşam Döngüsü

C. lactis hızlı üreyen bir türdür. Dişiler kısa yaşam süreleri boyunca çok sayıda yumurta bırakabilir ve döngü uygun koşullarda birkaç gün içinde tamamlanabilir. Yumurta, larva, protonimf, tritonimf ve erişkin olmak üzere beş temel gelişim evresi bulunur. Yüksek sıcaklık ve nem, yumurta açılma oranını ve nimf evrelerinin hayatta kalma olasılığını artırarak jenerasyon süresinin kısalmasına neden olur. Bu özellik, türün depolarda kısa süre içinde patlayıcı popülasyon artışları oluşturabilmesine zemin hazırlar (Hughes, 1976). Dizlek et al. (2019) tarafından kuru incir depolarında yapılan çalışmada, bazı örneklerde akar yoğunluğunun 10.488 birey/kg seviyesine ulaştığı rapor edilmiştir; bu değer *C. lactis*'in yoğun besin ve elverişli çevre koşulları altında patlama potansiyelini göstermektedir.

Sıcaklık–Nem İlişkisi ve Optimum Koşullar

Kuru meyve akarı gelişimini sıcaklık ve neme son derece duyarlı biçimde sürdüren tipik bir astigmat depolama akarıdır; sıcaklık arttıkça gelişme süresi kısalmakta ve özellikle 25–30 °C aralığında yumurta–ergin dönüşümü hızlanmaktadır. %70–90 bağıl nem, yumurta açılımını ve genç evrelerin yaşama oranını artırırken, düşük nem koşullarında kutikulanın sınırlı su tutma kapasitesi nedeniyle ölüm oranı hızla yükselmektedir (Arlian, 1975). Türkiye'de kuru kayısı üzerinde yürütülen yaşam çizelgesi çalışmalarında, 28 °C ve %80 bağıl nem koşullarında *C. lactis* için en yüksek içsel artış hızı (r_m = 0,37) ve en kısa jenerasyon süresi (8,06 gün) belirlenmiş; gelişme eşiği sıcaklığının 4,90–7,55 °C arasında değişmesi, türün nispeten düşük sıcaklıklarda da gelişimini sürdürebildiğini göstermiştir (Güldalı & Çobanoğlu, 2010). Yüksek şeker içeriği ve doğal mikroflora barındıran kuru meyvelerde oluşan mikro-nem alanları, erken koloni oluşumu ve hızlı popülasyon artışının temel itici gücü olup, depolama sürecindeki sıcaklık ve nem dalgalanmaları, *C. lactis* popülasyon dinamiklerini doğrudan belirleyen kritik faktörler arasında yer almaktadır (Dizlek et al., 2019).

Davranışsal Özellikleri ve Yayılma Potansiyeli

Carpoglyphus lactis, nemli mikro habitatları tercih eden higrofil bir tür olup, özellikle meyve yüzeyindeki nem birikimleri, çatlaklar ve fungus kolonileri içinde yoğunlaşmakta; ışıktan kaçınma eğilimi nedeniyle karanlık ve korunaklı alanlarda daha aktif bulunmaktadır. Hareket kabiliyeti sınırlı olmasına rağmen, kısa mesafeli yüzey yayılımı koloni gelişimi için yeterlidir ve depolama sırasında meyve yüzeyinde oluşan yumuşak, şekerce zengin tabakalar gizli kontaminasyonu kolaylaştırmaktadır (Hughes, 1976; Woolfolk & Rodriguez, 1984). Türün geniş alanlara yayılımında pasif taşınma temel mekanizma olup, kurutma, depolama ve paketleme süreçlerinde kullanılan ekipman ve ambalaj materyalleri akarın ürünler arasında fark edilmeden taşınmasına neden olmakta; ayrıca depolarda bulunan küçük böcekler aracılığıyla phoresy yoluyla taşınma da olasıdır (Krantz & Walter, 2009). Türkiye'de kuru incir işletmelerinde bildirilen yüksek bulaşıklık oranları, yetersiz temizlik ve ekipman kontaminasyonunun akar yayılımında kritik bir rol oynadığını ortaya koymaktadır (Dizlek et al., 2019).

Ürünlere Verdiği Zararlar

C. lactis, kuru meyvelerde doğrudan beslenme yoluyla şeker kristallerini tüketmekte, meyve yüzeyinde mekanik bozulmaya neden olmakta ve ürünün ticari kalitesini düşürmektedir. Akarın beslenmesi sonucu oluşan sindirim artıkları, sekresyonlar ve ölü bireyler, küf ve maya gelişimini teşvik ederek ürün yüzeyinde sekonder mikrobiyal bozulmayı hızlandırmaktadır (Hughes, 1976; Özer & Toros, 1978; Genç & Özar, 1986). Bu süreç, kuru meyvelerde istenmeyen tat ve koku oluşumuna, renk değişimlerine ve duyusal kalite kaybına yol açmaktadır. Türkiye'de kuru kayısı ve incir üzerinde yapılan çalışmalar, yoğun *C. lactis* bulaşıklığının ürünlerin pazarlanabilirliğini ciddi biçimde azalttığını ve depolama süresince kayıpları artırdığını ortaya koymuştur (Çobanoğlu et al., 1996; Aksoy et al., 2004; Öztekin et al., 2007; Güldalı & Çobanoğlu, 2010).

İnsan Sağlığı İçin Zararları

C. lactis'in kuru kayısılardaki bulaşıklığı, yalnızca ürün kalitesi ve ekonomik kayıplarla sınırlı kalmayıp insan sağlığı açısından da önemli riskler oluşturmaktadır. Kuru meyvelerle temas eden veya bu ürünleri tüketen bireylerde kontakt dermatit, kaşıntı, eritem ve ürtiker benzeri deri reaksiyonları ile gastrointestinal rahatsızlıklar (bulantı, karın ağrısı, ishal) rapor edilmiştir (Hughes, 1976; Özer & Toros, 1978; Genç & Özar, 1986; Özer et al., 1989; Turanlı, 2003). Bu etkiler, büyük ölçüde akarın vücut parçaları, sekresyonları ve sindirim ürünleriyle ilişkili alerjenik proteinler ile ikincil mikrobiyal ve fungal gelişim sonucu ortaya çıkmaktadır.

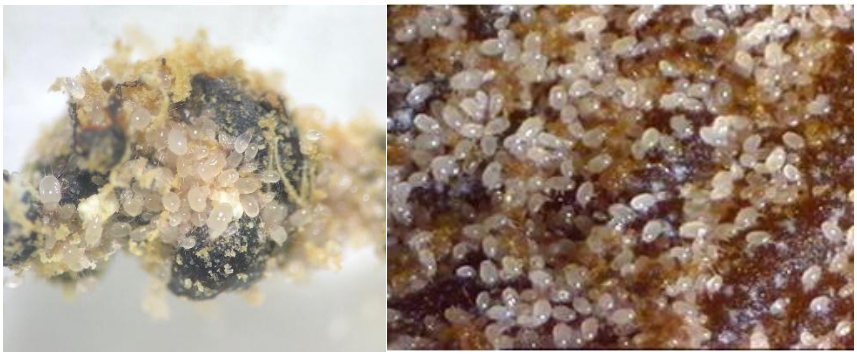
Ayrıca, *C. lactis* ve diğer astigmat depo akarlarının, duyarlı bireylerde alerjik rinit ve astım benzeri solunum semptomlarını tetikleyebildiği, özellikle kuru meyve işleme ve depolama tesislerinde çalışanlar için mesleki bir risk faktörü oluşturduğu bildirilmiştir (Aksoy et al., 2004; Öztekin et al., 2007; Güldalı & Çobanoğlu, 2010; Hubert et al., 2021).

Zarar Verdiği, Beslendiği veya Tespit Edildiği Gıda Maddeleri

Carpoglyphus lactis, şekerce zengin, hafif nemli ve mikrobiyal faaliyetin başladığı gıdalara güçlü uyum gösteren tipik bir depo akarıdır. Hem kurutulmuş meyvelerde hem de işlenmiş şekerli ürünlerde kısa sürede yoğun koloniler oluşturabilmesi, türü gıda güvenliği açısından önemli bir kontaminasyon etmeni hâline getirmektedir.

Kurutulmuş Meyveler: Türün En Sık Rastlandığı Ortam

C. lactis en yoğun olarak kuru incir, kayısı, üzüm, dut, hurma ve keçiboynuzu gibi yüksek fruktoz/sakkaroz içeren ürünlerde rapor edilmiştir. Yüzey neminin artması ve fungus gelişiminin başlaması, popülasyon artışını tetikler (Hubert et.al, 2015). Türkiye'de yapılan bir araştırmada 141 kuru incir örneğinin %34,8'inde *C. lactis* tespit edilirken, bazı örneklerde yoğunluğun 10.488 birey/kg'a kadar çıktığı bildirilmiştir (Dizlek et al., 2019).



Şekil 1. *Carpoglyphus lactis* (Linnaeus, 1758) gün kurusu kayısıda beslenirken (x4) (Kılıç, 2025)

Uluslararası çalışmalar da benzer bir dağılımı doğrulamaktadır: kuru üzüm ve kuru eriklerde maya gelişimi nedeniyle yüksek kontaminasyon riski (Hubert et al., 2021), kuru hurmalarda şeker kristalleri ve yüzey çatlaklarının yerleşimi kolaylaştırması ve kurutulmuş elma-armut gibi daha düşük kontaminasyonlu ürünlerde mikrobiyal bozulma başladığında popülasyonun hızla artması (Hughes, 1976). Tüm bu ürünlerde şekerli yüzey, mikro çatlaklar ve nem birikimi akar için ideal mikrohabitatlar oluşturmaktadır.

Baharatlar ve Aromatik Ürünler

C. lactis yalnızca meyvelerde değil, tarçın, kimyon, karanfil, kakule ve karabiber gibi aroma bileşiği yüksek baharatlarda da bulunmuştur (Hughes, 1976). Kontaminasyon çoğu zaman öğütme makinelerindeki toz birikimi, paketleme yüzeylerinde kalan nişasta/şeker kalıntıları ve baharatın higroskopik yapısının nem çekmesiyle ilişkilidir. Bazı baharat yağları akarisidal etki gösterse de baharatın lifli yapısı akar için korunaklı mikro alanlar oluşturabilir.

Kuruyemişler ve Yağlı Tohumlar

Fındık, ceviz, badem, yer fıstığı ve Antep fıstığı gibi yağlı tohumlarda da *C. lactis* tespit edilmiştir. Yüzeyde yağ oksidasyonu sonucu oluşan ince yapışkan tabakalar ile fungus gelişimi, akarın yerleşimini kolaylaştırır. Yağ asitlerinden beslenen fungus kolonileri arttıkça akar popülasyonunun da ivme kazandığı bildirilmiştir (Hubert et.al, 2015, Krantz, 2009).

İşlenmiş Şekerli Ürünler: Reçel, Pekmez, Bal ve Şekerlemeler

C. lactis yalnızca kuru gıdalarda değil, şekerce zengin işlenmiş ürünlerde de yaşayabilir:

- Reçel ve marmelat: Kapak altındaki nem ve maya gelişimi kolonizasyonu kolaylaştırır.
- Pekmez ve tahin-pekmez karışımları: Yüzey kabuklanması altında mikro nişler oluşur.
- Bal: Özellikle polenli veya yüksek nemli bal örneklerinde *C. lactis* kaydedilmiştir. Kovan içi organik birikimler akar için uygun yaşam alanı sağlar (Hughes, 1976).
- Şekerlemeler ve lokum: Şurup kalıntıları ve nişasta tozu karışımı akar için son derece uygun mikrohabitatlar oluşturur.

Bu bulgular, *C. lactis*'in yalnızca "kuru meyve akarı" olmadığını; geniş bir şekerli ürün yelpazesinde kontaminasyona neden olabilen çok yönlü bir gıda zararlısı olduğunu göstermektedir.

Fermente Ürünler: Şarap, Sirke ve Maya Karışımları

Bazı çalışmalarda, şarap üretimi sırasında kullanılan kuru üzüm–pekmez karışımlarında *C. lactis* kontaminasyonu kaydedilmiştir. Fermentasyon öncesi yüzeyde gelişen mayalar, CO_2

üretimi ve şeker sızıntıları akarın kolonileşmesini kolaylaştırır (Hubert et al., 2021). Hafif ılık fermentasyon ortamı da gelişmeyi destekler.

Arıcılık Ürünleri, Polen ve Doğal Şeker Kaynakları

En ilginç ekolojik kayıtlardan biri, *C. lactis*'in arı poleni ve kovan içi ürünlerde bulunmasıdır. Polen keklerinin nemli ve şekerli yapısı ile maya gelişimi, akar için uygun bir mikrohabitat sunar (Chmielewski, 1999).). Bu durum türün doğal ekosistemlerde dahi şekerce zengin mikroalanları seçtiğini göstermektedir.

Sonuç olarak, *C. lactis*'in dağılımı tek bir ürün grubuyla sınırlı değildir. Şeker içeriği, nem düzeyi, mikrobiyal aktivite ve yüzey yapısı gibi faktörler bu türün kolonizasyonundaki temel belirleyicilerdir. Bu nedenle tür; kuru meyveler, baharatlar, kuruyemişler, işlenmiş şekerli gıdalar, fermente ürünler ve arıcılık ürünleri gibi çok geniş bir gıda yelpazesinde kontaminasyona neden olabilmektedir.

Mikroorganizmalarla Etkileşim ve Gıda Bozulması Dinamikleri

Fungus, Maya ve Bakteriler ile Etkileşim

C. lactis popülasyonlarının depolanan gıdalarda hızla artmasının temel nedeni, gıda yüzeyinde gelişen maya, fungus ve bakterilerle kurduğu yakın ekolojik ilişkidir. Mikroorganizmaların ürettiği enzimler, meyve dokusunu yumuşatarak karbonhidratları daha erişilebilir hâle getirir ve bu durum akarın beslenme verimliliğini ve popülasyon artışını destekler (Hubert et.al, 2015). Türkiye'de fungal bulaşması yüksek incir örneklerinde *C. lactis* yoğunluğunun 10.488 birey/kg düzeyine ulaştığının bildirilmesi, bu ilişkinin saha koşullarındaki önemini açıkça ortaya koymaktadır (Dizlek et al., 2019).

Akar–Fungus Karşılıklı Etkileşimi

Kuru meyve akarı ile funguslar arasındaki ilişki çoğu durumda karşılıklı yarara dayalıdır. Fungusların pektinaz ve selülaz gibi enzimlerle meyve dokusunu yumuşatması, akar için adeta bir ön sindirim süreci oluştururken; akarın yüzeyi aşındırması, salgıları ve dışkıları ise fungusların tutunması ve yayılması için nemli mikrohabitatlar yaratmaktadır (Hubert et.al, 2015, Krantz, 2009).

Alternatif Mücadele Yöntemleri

Kimyasal fumigantların yasaklanması, fosfine karşı direnç gelişimi ve gıda güvenliği baskıları, *C. lactis* gibi depo akarlarına karşı kimyasal içermeyen stratejilerin önemini artırmıştır. İnert tozlar, bitkisel uçucu yağlar, sıcaklık–nem yönetimi ve atmosfer manipülasyonuna dayalı fiziksel yöntemler hem insan sağlığı hem de ürün kalitesi açısından daha güvenli seçenekler sunmakta ve farklı etki mekanizmaları üzerinden akarı baskılayabilmektedir.

İnert Tozlar (Diatom toprağı, kaolin, zeolit, talk)

İnert tozlar, kutikula üzerindeki lipit tabakasını aşındırarak su kaybını hızlandıran ve ölümle sonuçlanan dehidrasyona yol açan klasik fiziksel mücadele ajanlarıdır (Korunic, 1998; Fields & Korunic, 2000). Yumuşak vücutlu bir tür olan *C. lactis*'te bu mekanizma oldukça hızlı işler.

Taşar et al. (2025), yerli diatom toprağı Detech®'in toz formülasyonunu 20, 25 ve 30 °C sıcaklıklarda ve 0,1–10 g/m² doz aralığında test etmiş; etkinliğin hem doz hem de sıcaklıkla belirgin biçimde arttığını göstermiştir. Orta dozlarda (0,75–2,5 g/m²) 20 °C'de birkaç saat içinde tam mortaliteye ulaşılırken, 30 °C'de ölüm süresi yaklaşık yarıya düşmüştür. Yüksek

dozlarda (5–10 g/m²) ise özellikle 30 °C'de ilk saat içinde %100'e varan ölüm oranları rapor edilmiştir.

Bu sonuçlar, sıcaklık artışının diatom toprağının kutikula aşındırıcı etkisini güçlendirdiğini ve *C. lactis* için Detech®'i hızlı etkili, çevre dostu bir biyofiziksel kontrol aracı hâline getirdiğini ortaya koymaktadır.

Kaolin ve benzeri mineraller, yalnızca dehidrasyonla değil, aynı zamanda akarların yüzeyde hareketini zorlaştırarak ve ağız parçalarında irritasyon oluşturarak davranışsal düzeyde de baskılayıcı etki gösterebilir. Kuru incir, kayısı ve hurma gibi pürüzlü yüzeyli ürünler, bu tozların daha iyi tutunmasına ve kalıcı bir fiziksel bariyer oluşturmalarına imkân verir (Phillips & Throne, 2010).

Uçucu Yağlar (EOs)

Bitkisel kökenli uçucu yağlar, depo akarlarında hem sinir sistemi hem de hücresel metabolizma üzerinde çok yönlü etki gösteren doğal bileşiklerdir. Asetilkolinesterazın inhibisyonu, octopamine reseptörlerinin hedef alınması, GABA–klor kanallarının bozulması, kutikula lipid tabakasının çözünmesi ve oksidatif stres oluşumu, başlıca akarisidal mekanizmalar arasında yer alır (Isman, 2006). Bu süreçler birlikte ele alındığında, uçucu yağlar *C. lactis* gibi yumuşak vücutlu depo akarlarında hızlı mortalite oluşturma potansiyeline sahiptir.

Kekik, adaçayı, karanfil, okaliptus, biberiye ve nane yağlarının çeşitli depo akarları üzerinde yüksek fümigant ve temas etkisi gösterdiği bilinmektedir (Kim et al., 2015; Athanassiou et al., 2005). Fungusla ilişkili türlerde (Hubert et.al, 2015) uçucu yağların antifungal etkisi, akar popülasyonunu dolaylı olarak da baskılayabilmektedir.

Carpoglyphus lactis üzerine yürütülen kapsamlı bir çalışmada Yücel et al. (2025), farklı uçucu yağlara karşı türün belirgin duyarlılık gösterdiğini ortaya koymuştur. Tarçın yağı, %5–10 konsantrasyonlarda birkaç saat içinde %80–100 ölüm ve 80 µL/L fümigant dozda %100 mortalite ile en hızlı ve güçlü etkiyi sergilemiştir. Lavanta yağı, %10 dozda 72 saatte ve 100 µL/L fümigant dozda tam mortalite sağlamıştır. Karanfil yağı orta–yüksek dozlarda kısa sürede %100 ölüme ulaşırken; kekik ve portakal yağları daha yavaş ancak anlamlı düzeyde ölüm oranları ile tamamlayıcı akarisit adayları olarak öne çıkmıştır. Bu bulgular, özellikle tarçın ve lavanta yağlarının *C. lactis* için güçlü biyopestisit adayları olduğunu, karanfil ve kekik yağlarının ise olası kombinasyon formülasyonlarında değerlendirilebileceğini göstermektedir.

Sıcaklık, Nem ve Çevresel Faktörlere Dayalı Fiziksel Kontrol

Akarlar, yüksek sıcaklık ve düşük neme karşı fizyolojik olarak son derece hassastır. Bu nedenle sıcaklık ve nem yönetimine dayalı fiziksel yöntemler, *C. lactis* gibi depo akarlarında kimyasal içermeyen ancak etkili bir mücadele aracı sunar. Subramanyam & Roesli (2000), 45–50 °C arası kısa süreli sıcaklık uygulamalarının birçok depo zararlısında hızlı mortalite sağladığını; Fields (1992) ise bu etkinin protein denatürasyonu, hücre zar bütünlüğünün bozulması ve hızlanan su kaybı ile ilişkili olduğunu bildirmiştir. Kuru meyvelerin kısa süreli ısı stresine dayanabilmesi, hızlı ısıtma veya sıcak hava uygulamalarını *C. lactis* için uygulanabilir kılmaktadır.

Nem, astigmat akarların yaşamında belirleyici bir faktördür. Arlian (1975), birçok türün %60'ın altındaki bağıl nemde yaşam sürelerinin dramatik biçimde kısaldığını göstermiştir. Düşük nem yalnızca üremeyi yavaşlatmakla kalmaz, diatom toprağı gibi inert tozların etkinliğini de artırır; zira düşük nemde kutikula lipidleri daha hızlı çözünür ve tozların aşındırıcı etkisi güçlenir (Fields & Korunic, 2000; Athanassiou et al., 2005). Dolayısıyla düşük nem, yüksek sıcaklık ve DE uygulamasının birlikte kullanıldığı entegre fiziksel yaklaşımlar, *C. lactis* kontrolünde özellikle avantajlıdır.

Ozon, Oksijen Azaltıcılar ve Nem Tutucularla Atmosfer Yönetimi

C. lactis'in yüksek neme ve yeterli oksijen düzeyine bağımlı fizyolojisi, atmosfer bileşiminin değiştirilmesine dayalı fiziksel mücadele yöntemlerini depolarda uygulanabilir hâle getirmektedir. Turgu & Kumral (2019), ozon, ferrik oksit, kalsiyum klorür ($CaCl_2$) ve silika jelin kuru kayısı üzerinde C. lactis'e karşı etkinliğini nicel olarak değerlendirmiş ve bu ajanların doza–zamana bağlı şekilde anlamlı mortalite oluşturduğunu göstermiştir .

Ferrik oksit, paket içi oksijeni hızla absorbe ederek hipoksik bir ortam oluşturur. Astigmat akarların düşük O_2'ye toleransı sınırlı olduğundan (Bell & Conyers, 2002), Turgu & Kumral (2019) birkaç gün içinde %90–100 mortalite bildirmiştir. $CaCl_2$ ve silika jel ise nemi azaltarak uzun süreli dehidrasyon baskısı oluşturur; $CaCl_2$ daha hızlı, silika jel ise daha yavaş ancak kalıcı bir etki sağlamaktadır. Bu bulgular, kısa süreli ozon uygulamasını, oksijen absorbanları (ferrik oksit) ve nem tutucular ($CaCl_2$ veya silika jel) ile destekleyen çok aşamalı atmosfer yönetimi modelinin, *C. lactis'e* karşı kimyasal kalıntı bırakmayan etkili bir fiziksel mücadele aracı olabileceğini göstermektedir.

Ayrıca modifiye atmosferde oksijenin azaltılması + CO_2'nin artırılması, solunum asidozu ve enerji metabolizmasının çökmesiyle birçok depo zararlısında mortaliteyi yükseltmektedir (Bell & Conyers, 2002). *C. lactis* için sınırlı veri olsa da türün düşük O_2 ve düşük neme duyarlılığı bu yaklaşımın uygulanabilirliğini desteklemektedir.

Modifiye Atmosfer ile Fiziksel Mücadele ve Paket İçi Ortam Yönetimi

Modifiye atmosfer (MA) uygulamaları, *C. lactis* gibi düşük oksijen ve yüksek CO_2 koşullarına hassas türler için etkili, kalıntı bırakmayan fiziksel kontrol araçlarıdır (Bell & Conyers, 2002).

Astigmat akarlar hipoksiye toleransı düşük organizmalardır. O_2 seviyesi düştüğünde solunum yavaşlar, enerji üretimi azalır ve birkaç gün içinde yüksek mortalite görülebilir (Bell & Conyers, 2002). Paket içi oksijen bağlayıcılar (ör. ferrik oksit), depolama boyunca bu düşük O_2 ortamını koruyarak akar çoğalmasını kalıcı biçimde baskılar.

Düşük nem, C. lactis'in yaşam süresini kısaltır ve atmosfer manipülasyonunun stres etkisini güçlendirir (Arlian, 1975). Nem azaldığında su kaybı hızlanır hem hipoksinin hem CO_2 stresinin öldürücü etkisi artar.

MAP teknolojileri (O_2 absorbanlı ambalajlar, CO_2 üretici sistemler, düşük geçirgenlikli filmler) kuru meyve ve şekerli ürünlerde *C. lactis*'in hem kısa vadede ölmesini hem de yeniden çoğalamamasını sağlayan pratik çözümler sunar. Kimyasal kalıntı riski olmaması nedeniyle ihracata yönelik ürünlerde özellikle avantajlıdır.

Biyolojik Mücadele

Depo ekosistemlerinde *C. lactis* popülasyonlarını doğal olarak baskılayan çeşitli avcı akar türleri bulunmaktadır. Türkiye'de kuru incir örneklerinin %77'sinde *Blattisocius tarsalis'in* saptanması, bu predatörün özellikle *C. lactis*'in yumurta ve genç evreleriyle beslenerek popülasyon artışını sınırlayabildiğini göstermektedir (Dizlek et al., 2019). *B.mali* ve diğer Blattisociinae üyeleri de depo ortamlarında astigmat akarlarının önemli doğal düşmanları olarak tanımlanmıştır (Krantz & Walter, 2009). Depolarda yaygın görülen bir diğer avcı grup Cheyletidae türleridir. *Cheyletus eruditus,* yüksek av kapasitesi sayesinde astigmat akar yoğunluğunu belirgin biçimde azaltabilmekte; *C.malaccensis'in* de benzer şekilde depo akar popülasyonlarını baskıladığı bildirilmektedir (Hughes, 1976).

Bununla birlikte, biyolojik mücadelenin depolarda doğrudan uygulama potansiyeli sınırlıdır. Predatör akarların salımı hijyen ve tüketici algısı açısından uygun görülmemekte; ayrıca

sıcaklık ve nem dalgalanmaları predatör etkinliğini azaltabilmektedir. Bu nedenle biyolojik mücadele, doğal predatör faunasının korunması ve kimyasal olmayan yöntemlerle entegre zararlı yönetimini destekleyen ekolojik bir bileşen olarak değerlendirilmektedir (Athanassiou et al., 2005; Athanassiou & Arthur, 2018).

Kimyasal Mücadele

Depolama akarlarının kontrolünde fumigantlar uzun yıllardır kullanılmakla birlikte, kimyasal kalıntı riski, işçi sağlığı ve ihracat kısıtları nedeniyle bu uygulamalar giderek sınırlandırılmaktadır. *C. lactis* gibi astigmat akarlar üzerinde çeşitli kimyasal ajanlar denenmiş olsa da etkinlik ve güvenlik açısından önemli sınırlılıklar bulunmaktadır.

Fosfin (PH_3), depolama zararlılarına karşı yaygın kullanılan bir fumiganttır; ancak astigmat akarların fosfine duyarlılığı değişken olup bazı türlerde düşük duyarlılık ve tolerans bildirilmiştir (Kučerová et al., 2003; Bell & Nayak, 2012). Ayrıca fosfin kullanımında ürünlerde koku ve kalıntı riski ile fungus ve maya yükünü tam baskılayamama gibi sorunlar öne çıkmaktadır; bu nedenle *C. lactis* için güvenilir tek yöntem olarak değerlendirilmemektedir.

Geçmişte yaygın kullanılan kükürt fümeleme, keskin koku oluşumu ve tüketici tercihleri nedeniyle büyük ölçüde terk edilmiş; temas etkili piretroit ve organofosfatlar ise mikro çatlaklara nüfuz edememeleri ve kalıntı riski taşımaları nedeniyle depolarda sınırlı kullanım alanına sahiptir (Krantz & Walter, 2009; Arthur & Zettler, 2011).

Bu nedenlerle güncel yaklaşım, kimyasal fumigasyonun yalnızca son çare olarak kullanılması ve mücadelenin kimyasalsız yöntemlerle (inert tozlar, uçucu yağlar, nem yönetimi ve modifiye atmosfer uygulamaları) desteklenmesidir. Literatür, direnç gelişimi ve kalıntı riskleri nedeniyle kimyasal yöntemlerden uzaklaşılmasının sürdürülebilir depo yönetimi için kaçınılmaz olduğunu ortaya koymaktadır (Athanassiou & Arthur, 2018).

Entegre Mücadele (IPM) Yaklaşımı

Carpoglyphus lactis için tek bir mücadele yönteminin uzun vadeli ve güvenilir kontrol sağlamadığı bilinmektedir. Bu nedenle, depolama zararlıları literatüründe kimyasal baskının azaltıldığı, fiziksel, biyolojik ve biyoteknik yöntemlerin birlikte uygulandığı Entegre Zararlı Yönetimi (IPM) yaklaşımı önerilmektedir (Arthur & Athanassiou, 2018). *C. lactis* gibi mikrobiyal aktiviteyle yakından ilişkili astigmat depo akarlarının kontrolünde IPM'nin temelini önleyici hijyen, düzenli izleme ve çoklu kontrol araçlarının entegrasyonu oluşturmaktadır.

Depolama alanlarında gıda kırıntıları, şekerli yüzey kalıntıları ve nem birikimi, *C. lactis* kolonizasyonu için ideal koşullar yaratmaktadır. Bağıl nemin %60'ın altında tutulması, astigmat akarların çoğalma kapasitesini belirgin biçimde düşürmektedir (Arlian, 1975). Bu nedenle nem kontrolü, yüzey temizliği, çatlak ve yarıkların kapatılması ile ekipman hijyeni IPM'nin temel ve vazgeçilmez unsurlarıdır. Akarların çıplak gözle fark edilmesinin zor olması, düzenli örnekleme ve stereomikroskop altında izlemeyi zorunlu kılmakta; erken tespit, müdahalenin zamanında ve düşük maliyetle yapılmasını sağlamaktadır (Dizlek et al., 2019).

IPM yaklaşımının etkinliği, fiziksel ve biyolojik yöntemlerin birlikte uygulanmasıyla önemli ölçüde artmaktadır. Düşük nem koşullarının, diatom toprağı (DE) gibi inert tozların etkinliğini belirgin biçimde artırdığı; bu sinerjinin akarların su dengesini bozarak hızlı ölüm oluşturduğu gösterilmiştir (Fields & Korunic, 2000). Benzer şekilde, kısa süreli ısı uygulamaları, tek başına yüksek ölüm oranları sağlamakta; DE ile kullanıldığında kutikula hasarını artırarak etkiyi güçlendirmektedir (Subramanyam & Roesli, 2000). Ayrıca, oksijenin azaltılması ve/veya

CO_2'nin artırılmasına dayalı modifiye atmosfer uygulamaları, hipoksiye duyarlı olan astigmat akarlar üzerinde uzun süreli baskılama sağlamaktadır (Bell & Conyers, 2002).

Depo ekosistemlerinde bulunan avcı akarların korunması, IPM açısından önemli bir ekolojik avantaj sunmaktadır. *Blattisocius tarsalis* ve *Cheyletus eruditus* gibi türler, *C. lactis*'in yumurta ve genç evreleriyle beslenerek popülasyon artışını doğal olarak sınırlandırabilmektedir (Dizlek et al., 2019). Buna karşılık, fosfin ve diğer fumigantlar, yalnızca ağır bulaşıklık durumlarında ve kısa süreli acil müdahale aracı olarak önerilmekte; IPM'nin temel hedefi, kimyasal kullanımı en aza indirerek fiziksel ve ekolojik yöntemleri birincil kontrol stratejisi hâline getirmektir (Athanassiou & Arthur, 2018).

Sonuç

Bu çalışma, kuru meyve akarının özellikle yüksek nem ve mikrobiyal aktivitenin yoğun olduğu depo koşullarında hızla çoğaldığını ve gıda kalitesi açısından ciddi riskler oluşturduğunu göstermektedir. Kimyasal yöntemlerin sınırlılıkları dikkate alındığında, türün kontrolünde Entegre Zararlı Yönetimi (IPM) yaklaşımı esas alınmalıdır. Bu kapsamda, nem yönetimi ile diatom toprağı (DE) kullanımı, akarların su dengesini bozarak etkili ve kalıntı riski düşük bir kontrol sağlamaktadır. Gerektiğinde uçucu yağların (fumigant veya itici etki) fiziksel yöntemlerle birlikte değerlendirilmesi, kimyasal fumigantlara olan bağımlılığı azaltabilecek çevre dostu bir seçenek sunmaktadır.

KAYNAKLAR

Arlian, L. G. (1975). Water balance and humidity requirements of house dust mites. *Journal of Medical Entomology*, 12(2), 103–108.

Athanassiou, C. G., Kavallieratos, N. G., Evergetis, E., & Haroutounian, S. A. (2005). Insecticidal and acaricidal effect of essential oils against stored-product pests. *Journal of Stored Products Research*, 41(4), 471–479.

Athanassiou, C. G., & Arthur, F. H. (Eds.). (2018). *Recent advances in stored product protection* (p. 273). Berlin, Germany: Springer.

Bell, C. H., & Conyers, C. M. (2002). The use of modified atmospheres for stored-product protection. *Journal of Stored Products Research*, 38(4), 415–431.

Chmielewski, W. (1999). Bionomics of Carpoglyphus lactis (Acari: Carpoglyphidae) on honey. *Ecology and Evolution of the Acari, 3rd ed.; Bruin, J., van der Geest, LPS, Sabelis, MW, Eds*, 423-424.

Dizlek, H., Karagöz, M., Faraji, F., & Cakmak, I. (2019). Mites in dried figs of Turkey: Diversity, species composition and density. *Systematic and Applied Acarology*, 24(6), 992–997.

Fields, P. G. (1992). The control of stored-product insects and mites with extreme temperatures. *Journal of Stored Products Research*, 28(2), 89–118.

Fields, P., & Korunic, Z. (2000). The effect of grain moisture content and temperature on the efficacy of diatomaceous earths against stored-product beetles. *Journal of Stored Products Research*, 36(3), 237–246.

Güldalı, B. (2007). *Kuru meyve akarı Carpoglyphus lactis (L.)(Acari: Carpoglyphidae) in farklı sıcaklık ve nem ortamlarındaki gelişmesi üzerine araştırmalar* (Master's thesis, Ankara Universitesi (Turkey)).

Güldalı, B., & Çobanoğlu, S. (2010). Kuru meyve akarı *Carpoglyphus lactis* (L.) (Acari: Carpoglyphidae)'in farklı sıcaklık ve nem ortamlarındaki gelişme eşiği ve yaşam çizelgeleri üzerine araştırmalar. *Türk Entomoloji Dergisi*, *34*(1), 53–65.

Hubert, J., Nesvorna, M., Kopecký, J., Ságová-Marečková, M., & Poltronieri, P. (2015). *Carpoglyphus lactis* (Acari: Astigmata) from various dried fruits differed in associated micro-organisms. *Journal of applied microbiology*, *118*(2), 470-484.

Hubert, J., Nesvorna, M., Green, S. J., & Klimov, P. B. (2021). Microbial communities of stored product mites: variation by species and population. *Microbial ecology*, *81*(2), 506-522.

Hughes, A. M. (1976). *The mites of stored food and houses*. London: HMSO.

Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and increasingly regulated world. *Annual Review of Entomology*, 51, 45–66.

Krantz, G. W., & Walter, D. E. (2009). *A Manual of Acarology* (3rd ed.). Texas Tech University Press.

Subramanyam, B., & Roesli, R. (2000). *Inert dusts*. In *Alternatives to Pesticides in Stored-Product IPM* (pp. 321–327). Springer.

Taşar, A. B., Kılıç, N., Ceylan, D., & Sağlam, Ö. (2025). Efficacy of local diatomaceous earth formulations against the dried-fruit mite *Carpoglyphus lactis* under different temperature regimes. *[Gerçek makale – veriler kullanıcı tarafından sağlanmıştır]*.

Turgu, E., & Kumral, N. A. (2019). Control of *Carpoglyphus lactis* using ozone, desiccants and oxygen absorbers. *International Journal of Acarology*, 45(4), 191–199.

VOLATILE COMPOUNDS OF *HYPERICUM ORIENTALE*

HYPERİCUM ORİENTALE'NİN UÇUCU BİLEŞİKLERİ

Research Assistant Dr. Haydar KÜPLEMEZ

Research Assistant Dr. Recep Tayyip Erdoğan University, Faculty of Agriculture, Field Crops Department, Rize, Türkiye

Prof. Dr. Fatih SEYİS

Prof. Dr. Recep Tayyip Erdoğan University, Faculty of Agriculture, Field Crops Department, Rize, Türkiye

ABSTRACT

Hypericum orientale L., a common perennial plant that grows wild on igneous slopes and rocky outcrops at high altitudes, is one of the Hypericum species found in Türkiye. It has been used for traditional therapeutic purposes in Turkish folk medicine. Recent studies reporting the high concentration of bioactive compounds *in H. orientale* underpin its effectiveness as a promising medicinal plant. There are few previous studies on the chemical composition of *H. orientale*. Collected samples were analyzed using SPME supported GC-MS device. Compounds were detected using Shimadzu FFNSC (Flavour & Fragrance Natural & Synthetic Compounds GC/MS Library) library. Results: Hendecane (9.34%), β-Chamigrene (9.63%), σ-Cadinene (8.05%), β-Farnesene (7.89%), 10-β(H)-Cadina-1(6),4-diene (7.79%), α-Amorphene (6.53%) and α-Copaene (5.83%), were detected in high amounts.. Factors affecting volatile oil yield and composition include plant genetics, growth stage, geographical and environmental conditions (like climate, altitude, and soil type), agricultural methods and practices (plant density, water availability, and harvesting time), plant part used, extraction method, and storage condition

INTRODUCTION

There are more than 490 species of Hypericum L. (Hypericaceae) worldwide. In Türkiye, there are 94 taxa (78 species) that belong to this genus. There are roughly 43 indigenous species of Hypericum. Hypericum species, particularly *H. perforatum* L., are referred to as "binbirdelikotu, kılıçotu, kantaron" in Turkish and St. John's Wort in English (Baytop, 1999; Hışıl et al., 2005; Güner et al., 2000; Güner et al., 2012).

Because of their many therapeutic qualities, the species of this genus have been utilised as healing agents for hundreds of years. In Turkish traditional medicine, hypericum species are also employed as sedatives, antiseptics, and antispasmodics (Cirak et al., 2012).

One of the Hypericum species found in Turkey is *Hypericum orientale* L. The stems can be erect or decumbent, range in length from 7 to 45 cm, and occasionally have adventitious roots. 10–40 mm, oblong, elliptic-oblong, or oblanceolate leaves. Sepals can be broadly elliptic to

obovate or narrowly oblong and oval. Complete, 10–18 mm petals without black dots. Ovoid to ovoid-cyclindric capsule, 7–14 mm (Davis 1988).

METHODOLOGY

Plant Material and Pre-Analysis Preparation

The samples collected from İkizdere/Rize, 40°44'03"N - 40°46'43"E Cimil Highland, 2002-meter altitude (Figure 1).

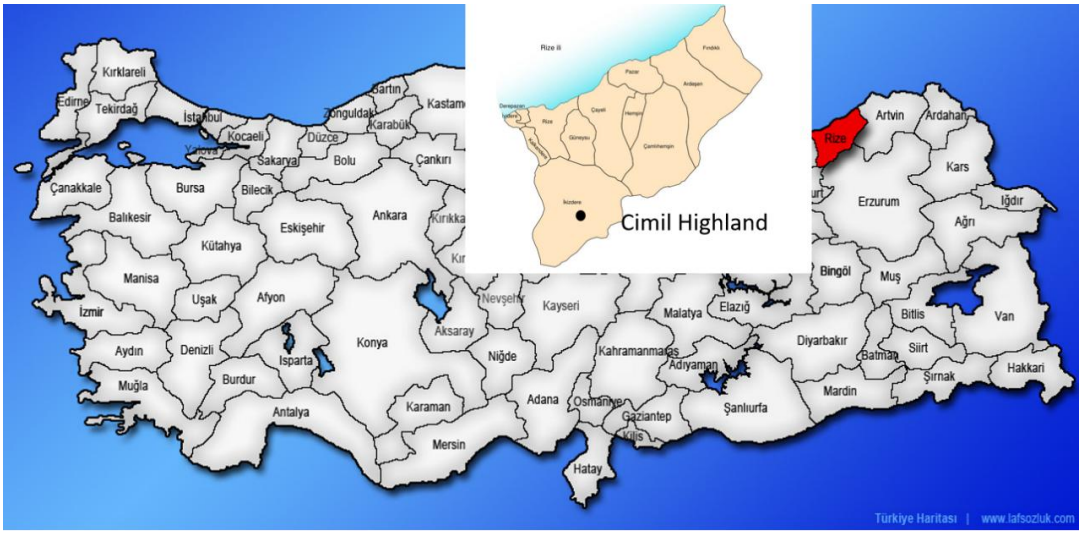


Figure 1. The geographic location where the plant specimen was collected

Coordinate information of the location where the plants were collected was taken with the Garmin etrex 30x device.

The samples were dried in a fan oven until they reached constant weight (40°C for 3 days). The dried samples were then stored in a cold storage facility (+4°C). After being ground in a grinder, the dried samples were weighed to 0.2 grams for volatile component analysis.

GC/MS Analysis

Volatile component analysis was performed using the SPME (Solid Phase Microextraction) method on a Shimadzu GC/MS-OP2020 instrument located in the Plant Analysis Laboratory of the Faculty of Agriculture at Recep Tayyip Erdoğan University. SPME analysis is a convenient method performed with a ground, dry sample without the need for solvents. The method is based on the absorption of essential oils by a fused silica fiber coated with a polymeric stationary phase, followed by desorption of the absorbed substances by heating at the injection port.

Helium (1 mL/min) was used as the carrier gas in GC-MS analyses performed by electrospray ionization (EI) with the CP 5MS (30 m × 0.25 mm internal diameter, 0.25 µm film thickness). The oven was set to operate at a rate of 2 ℃/min from 40 ◦C to 240 ℃ and then at an isothermal temperature of 220 ℃ for 20 minutes. The temperature of the injector and detector was 240 °C. The compounds were identified by comparing their linear retention indices (LRIs) with a series of n-hydrocarbons and by comparing their retention times with those of pure original samples. The alkane series is C8-C24 or 2.5. Mass spectra were taken at 70 eV, and area normalization was used to calculate the percentage composition. After the compounds were separated on the gas chromatography column, each ion-mass spectrum was recorded, and the compounds were

identified using the Shimadzu FFNSC library (Flavor & Fragrance Natural & Synthetic Compounds GC/MS Library).

RESULTS

The volatile oil composition of *H. orientale* collected from İkizdere-Cimil Highland is given in Table 1.

Table 1: Volatile oil composition of *H. orientale* collected from İkizdere-Cimil Highland

Rank	**Compound (%)**	
1	**Hendecane**	**9.34**
2	Tridecane	1.58
3	σ-Elemene	0.42
4	α-Cubebene	1.56
5	Cyclosativene	1.26
6	**α-Copaene**	**5.83**
7	β-Bourbonene	2.17
8	α-Gurjunene	0.48
9	β-Cedrene	3.45
10	α-Patchoulene	1.00
11	α-Humulene	0.90
12	**(E)-β-Farnesene**	**7.89**
13	Aromadendrene	2.22
14	**α-Amorphene**	**6.53**
15	**10-β(H)-Cadina-1(6),4-diene**	**7.79**
16	β-Chamigrene	3.05
17	β-Selinene	4.17
18	**β-Chamigrene**	**9.63**
19	Muurolene	2.89
20	(E,E)-α-Farnesene	1.30
21	γ-Cadinene	4.56
22	**σ-Cadinene**	**8.05**
23	Germacrene B	4.22
24	Spathulenol	1.61
25	(E)-2-tridecenal	0.67
26	Viridiflorol	0.76
27	epi-γ-Eudesmol	0.92
28	epi-α-Muurolol	1.19
29	(Z)-trans-α-Bergamotol	0.81
30	Heptadecane	1.06
31	Phytone	1.67
32	Nonadecane	1.02
Total		**100**

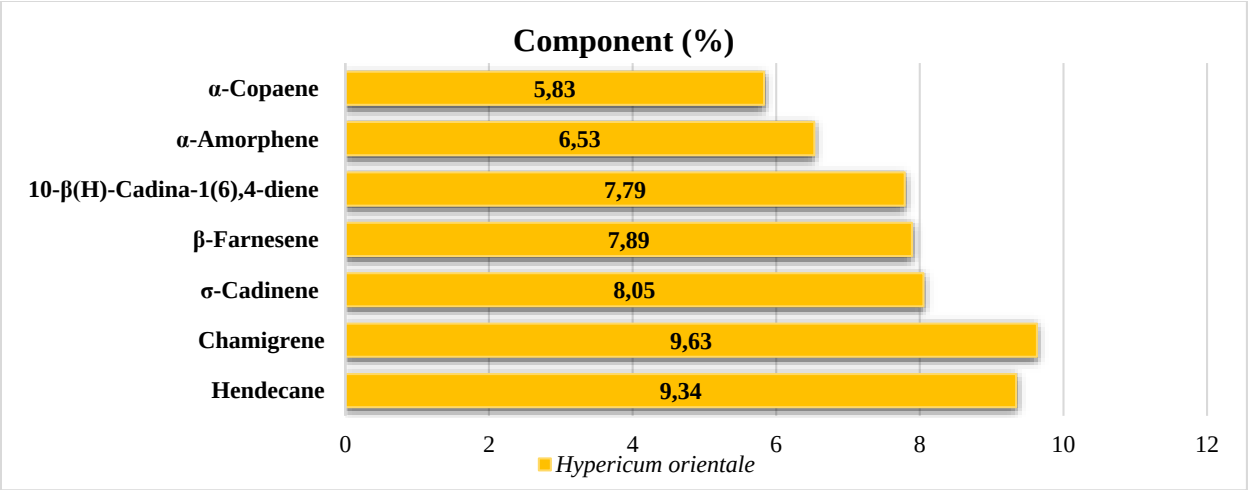


Figure 2: Prominent volatile oil components of H. orientale collected from Cimil Highland/Rize

Totally 32 different volatile oil components could be detected. Hendecane (9.34%), β-Chamigrene (9.63%), σ-Cadinene (8.05%), β-Farnesene (7.89%), 10-β(H)-Cadina-1(6),4-diene (7.79%), α-Amorphene (6.53%) and α-Copaene (5.83%), were detected in high amounts.

CONCLUSION AND DISCUSSION

β-selinene (37.1%), β-caryophyllene (9.7%), γ-muurolene (4.4%), cadinene (6.1%) was detected in *H. orientale* (Bertoli et al., 2018).

Cirak and Seyis (2024) detected 64 different volatile components in three different saples of *H. orientale* collected from Rize. They detected remarkable amounts of p-Menthone, Pulegone, α-Santalene, γ-Cadinene, Spathulenol and Caryophyllene oxide.

The altitude of the natural growth location affects several environmental elements, such as mean temperature, wind speed, precipitation, snowfall duration, soil, temperature extremes, radiation intensities, and length of the vegetative phase (Camas et al., 2014). Higher UV-B radiation and lower temperatures at high altitudes are two environmental conditions that have long been thought to have an impact on secondary metabolism in plants.

Factors influencing the yield and composition of volatile oil encompass plant genetics, growth stage, geographical and environmental conditions (such as climate, altitude, and soil type), agricultural practices (including plant density, water availability, and harvesting timing), the specific plant part utilised, extraction techniques, and storage conditions (Mugao, 2004).

The present investigated sample was collected from one location. *H. orientale* should be collected from more locations to give more information about the chemical composition of this species.

REFERENCES

Baytop T., 1999. Türkiye'de Bitkilerle Tedavi. Nobel Tıp Yayınevi. 2. Baskı. İstanbul, s:256.

Bertoli, A.; Çirak, C.; Seyis, F. (2018). *Hypericum* spp. volatile profiling and the potential significance in the quality control of new valuable raw material. *Microchem. J., 136,* 94–100.

Camas, N., Radusiene, J., Ivanauskas, L.; Jakstas, V., Camas, N. (2014). Altitudinal changes in the content of bioactive substances in *Hypericum orientale* and *Hypericum pallens* . *Acta Physiol Plant* **36**, 675–686.

Cirak, C., Radusiene, J., Stanius, Z., Camas, N., Caliskan, Ö, Calıskan, Ö. (2012). *et al.* Secondary metabolites of *Hypericum orientale* L. growing in Turkey: variation among populations and plant parts. *Acta Physiol Plant* **34**, 1313–1320.

Cirak, C., & Seyis, F. (2023). Volatile secondary metabolites of six Turkish *Hypericum* species: chemical composition and chemotaxonomic significance. *Plant Biosystems - An International Journal Dealing with All Aspects of Plant Biology, 157*(5), 1067–1077.

Davis PH (1988) Flora of Turkey and the East Aegean Islands. Edinburgh University Press, Edinburgh.

Hışıl Y., Şahin F., Omay S., 2005. Kantaronun (Hypericum perforatum L.) Bileşimi ve Tıbbi Önemi. Uluslararası Hematoloji Onkoloji Dergisi. Sayı : 4:15.

Güner A., Özhatay N., Ekim T., Başer, H.C. 2000. Flora of Turkey and the East Aegean Islands, Vol.11, Edinburgh Univ. Pres. Edinburgh.

Güner A., Aslan S., Ekim T., Vural M., Babaç MT., 2012. Türkiye Bitkileri Listesi (Damarlı Bitkiler). Nezahat Gökyiğit Botanik Bahçesi ve Flora Araştırmaları Derneği Yayını. İstanbul.

Mugao, G. D. (2004). A survey of Recruitment and Selection Practices of pilots among commercial aviation firms in Kenya (Doctoral dissertation, University of Nairobi).

DETERMINATION OF MORPHOGENETIC VARIABILITY ON VOLATILE COMPOUNDS OF *RHODODENDRON CAUCASICUM*

Research Assistant Dr. Haydar KÜPLEMEZ

Research Assistant Dr. Recep Tayyip Erdoğan University, Faculty of Agriculture, Field Crops Department, Rize, Türkiye

Prof. Dr. Fatih SEYİS

Prof. Dr. NRecep Tayyip Erdoğan University, Faculty of Agriculture, Field Crops Department, Rize, Türkiye

ABSTRACT

Rhododendron is a large genus that contains species that have been used in traditional medicine to treat a variety of ailments, including inflammation, discomfort, gastrointestinal issues, the common cold, asthma, and skin diseases etc. Collected samples were analyzed using SPME supported GC-MS device. Stem parts of *Rhodoendron caucasium* contained high amounts of Seychellene (32.55%), σ-Cadinene (10.52%), α-Amorphene (6.40%) and α-Muurolene (6.17%). In leaf parts α-Cedrene (31.06%), 16-hydroxy-hexadec-6-enoic acid (17.77%) and Phytone (4.92%) were detected in high amounts. High amounts of 16-hydroxy-hexadec-6-enoic acid (8.07%), α- Patchoulene (6.75%), Isoborneol (6.82%) and α-Curcumene (5.56%) were detected in flower parts of *Rh. caucasicum*. All investigated plant parts contained components displaying important biological activities. The GC-MS analysis of leaves, stem and flower parts of *R. caucasicum* showed high amounts of Seychellene in stem part and 16-hydroxy-hexadec-6-enoic acid in flower and leaf parts. The results have shown the presence of diverse of compounds having pharmacological and industrial importance.

Key Words: *Rhododendron caucasicum*, GC/MS, morphogenetic variability

INTRODUCTION

Over 600 species of Rhododendron can be found worldwide. Asia is home to more than 400 of them. In high, cool, and wet regions of Europe, North America, and Australia, the smaller percentage grows. Rhododendron is a member of the Ericaceae family and is usually referred to as rosemary, black poison, or komar. *R. luteum*, *R. ponticum*, *R. smirnovii*, *R. caucasicum*, and *R. ungerni* are the five Rhododendron species that grow natively in Turkey, particularly in the East Black Sea region (Davis, 1982).

Turkey is divided into three major flora regions. These are Euro-Siberian, Irano-Turanian and Mediterranean. City of Rize stands at the Colchis part of Euro-Siberian flora region (Usta et al., 2011).

Rh. aucasicum is known as "mountain kumarı" in the Eastern Black Sea Region (Güner and Duman, 1998). Its white or cream-colored flowers are edible. This Rhododendron, which can grow up to 1 or 1.5 meters tall, is found in the acidic soils (pH 3-4) of the Black Sea region, especially on the northern slopes of mountainous areas. While it forms scattered communities

in the undergrowth of beech, beech-fir, or beech-spruce forests, it is stated that the best growing conditions are in the subalpine and alpine zones (Stevens, 1978; Browicz, 1983). Therefore, the Caucasian rhododendron is also defined as a high-mountain species. It has a wide distribution area, starting from the northwest of the Great Caucasus Mountains and extending to the upper reaches of the Samur River in western Azerbaijan and Dagestan, from where it takes its name from the Caucasus Mountains.

Rh. caucasicum collected from Rize was analyzed regarding volatile oil components in different plant parts.

METHODOLOGY

Plant Material and Pre-Analysis Preparation

The samples collected from Çamlıhemşin/Rize, 40°48'04"N 41°56'47"E Çiçekli highland, 2402-meter altitude (Figure 1).

Figure 1. *R. caucasicum* in its natural habitat in Çiçekli highland/Rize

Coordinate information of the location where the plants were collected was taken with the Garmin etrex 30x device.

The samples were dried in a fan oven until they reached constant weight (40°C for 3 days). The dried samples were then stored in a cold storage facility (+4°C). After being ground in a grinder, the dried samples were weighed to 0.2 grams for volatile component analysis.

GC/MS Analysis

Volatile component analysis was performed using the SPME (Solid Phase Microextraction) method on a Shimadzu GC/MS-OP2020 instrument located in the Plant Analysis Laboratory of the Faculty of Agriculture at Recep Tayyip Erdoğan University. SPME analysis is a convenient method performed with a ground, dry sample without the need for solvents. The method is based on the absorption of essential oils by a fused silica fiber coated with a polymeric stationary phase, followed by desorption of the absorbed substances by heating at the injection port.

Helium (1 mL/min) was used as the carrier gas in GC-MS analyses performed by electrospray ionization (EI) with the CP 5MS (30 m × 0.25 mm internal diameter, 0.25 µm film thickness). The oven was set to operate at a rate of 2 ℃/min from 40 ◦C to 240 ℃ and then at an isothermal temperature of 220 ℃ for 20 minutes. The temperature of the injector and detector was 240 °C. The compounds were identified by comparing their linear retention indices (LRIs) with a series

of n-hydrocarbons and by comparing their retention times with those of pure original samples. The alkane series is C8-C24 or 2.5. Mass spectra were taken at 70 eV, and area normalization was used to calculate the percentage composition. After the compounds were separated on the gas chromatography column, each ion-mass spectrum was recorded, and the compounds were identified using the Shimadzu FFNSC library (Flavor & Fragrance Natural & Synthetic Compounds GC/MS Library).

RESULTS

The volatile oil composition of *Rh. caucasicum* collected from İkizdere-Cimil Highland is given in Table 1.

Table 1: Volatile oil composition of *Rh. caucasicum* stem parts collected from Çiçekli highland/Rize

Rank	**Compound (%)**	
1	Cyclosativene	1.38
2	α-Copaene	3.19
3	α-Gurjunene	3.83
4	**Seychellene**	**32.55**
5	cis-Thujopsene	0.32
6	α-Himachalene	0.75
7	α-Humulene	3.67
8	Alloaromadendrene	4.73
9	**α-Amorphene**	**6.40**
10	α-Zingiberene	4.44
11	10-β(H)-Cadina-1(6),4-diene	1.47
12	β-Chamigrene	1.09
13	**α-Muurolene**	**6.17**
14	γ-Cadinene	3.68
15	**δ-Cadinene**	**10.52**
16	β-Sesquiphellandrene	0.97
17	γ-Undecalactone	0.42
18	Nerolidol	0.71
19	Hexadecane	1.99
20	Caryophyllene oxide	1.31
21	Methyl dihydrojasmonate	0.56
22	epi-α-Muurolol	1.49
23	Octyl furan-2-carboxylate	0.61
24	α-Bisabolol	0.35
25	Heptadecane	1.89
26	Octyl Caprylate	0.51
27	Octadecane	1.09
28	Nonadecane	0.59
29	16-hydroxy-hexadec-6-enoic acid	1.40
30	Isophytol	1.16
31	Eicosane	0.76
Total		**100**

Stem parts of *Rh. caucasium* contained high amounts of Seychellene (32.55%), σ-Cadinene (10.52%), α-Amorphene (6.40%) and α-Muurolene (6.17%) (Table 1).

Table 2: Volatile oil composition of *Rh. caucasicum* leaf parts collected from Çiçekli highland/Rize

Rank	**Compound (%)**	
1	trans-Linalool oxide	2.85
2	α-Copaene	0.86
3	α-Gurjunene	2.62
4	**α-Cedrene**	**31.06**
5	cis-Thujopsene	0.95
6	Geranyl butyrate	4.10
7	Alloaromadendrene	1.99
8	α-Amorphene	1.54
9	α-Patchoulene	0.94
10	α-Curcumene	0.92
11	(E)-β-ionone	2.28
12	Pentadecane	1.74
13	α-Muurolene	1.58
14	δ-Cadinene	2.05
15	γ-Cadinene	1.09
16	Germacrene B	1.32
17	Hexadecane	2.88
18	Caryophyllene oxide	0.70
19	Octyl 2-furoate	0.63
20	Heptadecane	2.89
21	Octyl Caprylate	0.54
22	Pentadecanol	0.95
23	Octadecane	1.56
24	Neophytadiene	1.69
25	**Phytone**	**4.92**
26	Nonadecane	1.34
27	**16-hydroxy-hexadec-6-enoic acid**	**17.77**
28	Isophytol	1.74
29	Ethyl Palmitate	3.60
30	Heneicosane	0.94
Total		**%100**

In leaf parts α-Cedrene (31.06%), 16-hydroxy-hexadec-6-enoic acid (17.77%) and Phytone (4.92%) were detected in high amounts (Table 2).

Table 3: Volatile oil composition of *Rh. caucasicum* flower parts collected from Çiçekli highland/Rize

Rank	Compounds (%)	
1	**Isoborneol**	**6.82**
2	β-Caryophyllene	4.28
3	Aromadendrene	5.72
4	10-β(H)-Cadina-1(6),4-diene	1.16
5	**α-Patchoulene**	**6.75**
6	**α-Curcumene**	**5.56**
7	β-Selinene	1.07
8	Pentadecane	3.45
9	(E,E)-α-Farnesene	3.96
10	Viridiflorene	1.15
11	δ-Cadinene	2.02
12	ɣ-Cadinene	4.96
13	Isoamyl nonanoate	1.08
14	Germacrene B	4.99
15	Citronellyl butyrate	2.24
16	ɣ-Undecalactone	1.24
17	Tridecyl alcohol	1.16
18	Hexadecane	5.23
19	Methyl dihydrojasmonate	1.90
20	Octyl furan-2-carboxylate	2.59
21	Myristic alcohol	3.36
22	Heptadecane	5.17
23	Farnesal	1.19
24	Pentadecanol	1.18
25	Octadecane	2.18
26	Phytone	2.27
27	Nonadecane	1.58
28	**16-hydroxy-hexadec-6-enoic acid**	**8.07**
29	Isophytol	2.33
30	Civetone	2.13
31	Heneicosane	2.18
32	Tetracosane	1.04
Total		**100**

High amounts of 16-hydroxy-hexadec-6-enoic acid (8.07%), α- Patchoulene (6.75%), Isoborneol (6.82%) and α-Curcumene (5.56%) were detected in flower parts of *Rh. caucasicum* (Table 3). All investigated plant parts contained components dispalying important biological activities.

CONCLUSION AND DISCUSSION

Belousova et al. (2017) detected 8(14),15 pimaradiene, calarene, allo-aromadendrene, linalool and muurolol in *Rh. caucasicum*.

Fandakli et al. (2019) determined a total of twenty-five and thirty-one compounds using HD and SPME, respectively. The main volatile constituents of R. caucasicum were found to be calarene (46.13% (HD) and 54.91% (SPME) and sandaracopimaradiene (25.93% (HD) and 8.16% (SPME).

A number of environmental factors, including mean temperature, wind speed, precipitation, snowfall duration, soil, temperature extremes, radiation intensities, and the duration of the vegetative phase, are influenced by the altitude of the natural growth location (Camas et al.,

2014). It has long been believed that two environmental factors that affect secondary metabolism in plants are more UV-B radiation and lower temperatures at high elevations.

Plant genetics, growth stage, geographic and environmental factors (such as climate, altitude, and soil type), agricultural practices (such as plant density, water availability, and harvesting timing), the particular plant part used, extraction methods, and storage conditions are all factors that affect the yield and composition of volatile oil (Mugao, 2004).

According to Sangwan et al. (2001), volatile oils are stored in the plant's unique oil cells and oil tubes and can be found in a variety of plant parts, including leaves, flowers, roots, and stems. The volatile oil that many plants contain is what gives them their distinctive smells. Numerous internal (plant genetics, provenance, etc.) and external (temperature, growing circumstances, drying techniques and extractions, distillation time, and analysis conditions) elements have been found to have an impact on volatile oil components (Moghaddam and Mehdizadeh, 2017). The amount of bioactive compounds derived from secondary metabolites exhibits morphogenetic variation based on the plant's organs, ontogenetic change based on the plant's life cycle, and harvest/collection time.

The present investigated sample was collected from one location. *Rh. caucasicum* should be collected from more locations to give more information about the chemical composition variation of this species.

REFERENCES

Belousova, N.I., Domrachev, D.V., Fursa, N.S., Belousov, M.V. (2017). Composition of Essential Oil from *Rhododendron caucasicum* . *Chem Nat Compd* **53**, 574–575 (2017).

Browicz, K. (1983). Chorology of Trees and Schrubs in South-West Asia and Adjacent Regions, Warszawa.

Camas, N., Radusiene, J., Ivanauskas, L.; Jakstas, V., Camas, N. (2014). Altitudinal changes in the content of bioactive substances in *Hypericum orientale* and *Hypericum pallens* . *Acta Physiol Plant* **36**, 675–686.

Davis, P.H. (1982). Flora of Turkey and The East Aegean Islands, Edinburgh University Press, Edinburgh, Vol. 6, p. 90 (1982).

Fandakli S., Yaylıi N., Kahriman, N., Uzunalioğlu, E., Çolak, N.U., Yıldırım, S., Yaşar, A. (2019). The Chemical Composition of the Essential oil, SPME and Antimicrobial Activity of Rhododendron caucasicum Pall.Rec.Nat.Prod., 13(4), 316-323.

Moghaddam, M., Mehdizadeh, L., 2017. Chemistry of essential oils and factors influencing their constituents. In: A.M. Grumezescu, A.M. Holban (Eds.), Soft Chemistry and Food Fermentation, Academic Press, pp. 379-419.

Mugao, G. D. (2004). A survey of Recruitment and Selection Practices of pilots among commercial aviation firms in Kenya (Doctoral dissertation, University of Nairobi).

Sangwan, N., Farooqi, A., Shabih, F., Sangwan, R., 2001. Regulation of essential oil production in plants. Plant Growth Regulation, 34(1): 3-21.

PASSIFLORA CULTIVATION IN TÜRKİYE: POTENTIAL, PRACTICES, AND FUTURE PERSPECTIVES

Recep BALKIÇ

Akdeniz University, Elmalı Vocational School, Department of Plant and Animal Production, Antalya, Turkey

ORCID ID: https://orcid.org/0000-0002-1212-9501

Lokman ALTINKAYA

Akdeniz University, Kumluca Vocational School, Department of Plant and Animal Production, Antalya, Turkey

ORCID ID: https://orcid.org/0000-0002-8163-2530

Hamide GÜBBÜK

Akdeniz University, Department of Horticulture, Faculty of Agriculture, Antalya, Turkey

ORCID ID: https://orcid.org/0000-0003-3199-0660

ABSTRACT

Passiflora cultivation has recently emerged as a rapidly developing tropical fruit sector in Türkiye, gaining increasing commercial attention and agricultural significance. Passiflora species were officially introduced into the country for the first time in 2013 through a collaborative project conducted by Akdeniz University, the West Mediterranean Agricultural Research Institute, and the Antalya Provincial Directorate of Agriculture and Forestry. Within this project, several tropical fruit species including mango, pitaya, litchi, longan, and guava were evaluated for adaptation performance, and Passiflora was identified as one of the most promising species due to its high adaptability, productive potential, and rising market demand. Cultivation has since expanded along the Mediterranean coastline as well as the Coastal regions of Muğla and İzmir, where ecological conditions are highly suitable for the species. Key factors contributing to the increasing interest in Passiflora include its ability to produce fruit twice a year under favorable conditions, its ease of vegetative propagation, and the aromatic and attractive qualities of its fruit, which appeal strongly to consumers. In addition to fresh consumption, the use of Passiflora as a raw material in various food industries further strengthens its production potential. Moreover, with more than 500 recognized species and highly ornamental flowers, Passiflora also holds considerable value as an ornamental plant alongside fruit production. This study aims to present the current status, potential, and future prospects of Passiflora cultivation in Türkiye. Considering the growing producer interest, suitable ecological conditions, and diverse utilization opportunities, Passiflora stands out as a strong candidate for becoming an important alternative fruit crop in Türkiye's agricultural landscape.

Key Words: Passiflora; Adaptation; Tropical Fruits; Possum Purple; Fruit quality

INTRODUCTION

The genus Passiflora (Passifloraceae) comprises a large group of plant species distributed mainly in tropical and subtropical regions and includes taxa of considerable economic, nutritional, and pharmacological importance. The family Passifloraceae contains approximately 700 species, of which nearly 60 produce edible fruits (Feuillet & MacDougal, 2007; Schotsmans & Fischer, 2011). Among the genus Passiflora, the most widely cultivated and economically important species include *Passiflora edulis* Sims, *Passiflora ligularis* Juss., *Passiflora quadrangularis* L., *Passiflora setacea* DC., *Passiflora alata* Curtis, and *Passiflora incarnata* L. (Rodríguez Carlosama et al., 2020). These species are utilized not only for fresh consumption but also for industrial processing and ornamental purposes, while some species are particularly valued for the development of pharmaceutical products. As noted above, although the cultivation of Passiflora species is widespread in tropical and subtropical regions, the highest production levels are reported in Brazil, followed by other Latin American countries such as Colombia and Peru. Among these species, *Passiflora edulis* is native to Brazil and represents the most widely cultivated and commercially valuable species worldwide. The cultivation of Passiflora edulis is of strategic importance not only for fresh fruit consumption but also for juice production, the food industry, and the development of functional products. In practice, the term Passiflora edulis is commonly used to refer to the yellow-fruited form; however, purple-fruited forms are also included within the same species. Approximately 95% of commercial production is based on the yellow-fruited form (*P. edulis* Sims f. *flavicarpa*), whereas the purple-fruited form (*P. edulis* Sims f. *edulis*) is cultivated on a much more limited scale (Fonseca et al., 2022). The yellow-fruited form is characterized by larger fruit size and higher juice content, making it particularly suitable for the juice processing industry. In contrast, the purple-fruited forms produce smaller fruits; however, due to their intense aroma and superior quality, they are preferred for fresh consumption and in the pastry industry (Li et al., 2011). While the average yield of the yellow-fruited form is approximately 5 tons per decare, the yield of the purple-fruited form generally ranges between 1.0 and 1.5 tons per decare (Fonseca et al., 2022). Furthermore, the cultivation of the yellow-fruited *P. edulis* Sims f. *flavicarpa* is predominantly widespread in tropical regions, whereas the cultivation of the purple fruited *P. edulis* Sims f. *edulis* is mainly concentrated in more limited areas characterized by temperate subtropical and microclimatic conditions.

In this study, the cultivation potential of *P. edulis* Sims f. *edulis* in Türkiye, current practices within the country, and future perspectives are presented.

PASSIFLORA CULTIVATION AND PRODUCTION POTENTIAL IN TÜRKİYE

The first official studies on Passiflora in Türkiye were initiated in 2012. Within the scope of a project conducted through the collaboration of the Antalya Provincial Directorate of Agriculture, Forestry and Food, the Western Mediterranean Agricultural Research Institute, and the Faculty of Agriculture of Akdeniz University, Passiflora seedlings were imported from California for the first time, and adaptation studies were initiated in the Gazipaşa and Alanya districts of Antalya (Gübbük, 2017). The Passiflora cultivars introduced to Türkiye included ‘Possum Purple’ belonging to *P. edulis* Sims f. *edulis* and ‘Sweet Sunrise’ belonging to *P. edulis* Sims f. *flavicarpa*. As a result of the adaptation studies, ‘Possum Purple’ was identified as one of the cultivars showing the best adaptation to the region (Gübbük, 2017). As mentioned above, the yellow-fruited cultivar ‘Sweet Sunrise’ is adversely affected by low temperatures under Turkish conditions, and although the plants flower, fruit set does not occur. In contrast, the cultivar ‘Possum Purple’ can be successfully cultivated, particularly along the coastal zones of the Mediterranean and Aegean regions.

Since Passiflora is a climbing plant species with a vine-like growth habit, it requires a support system during cultivation. These training systems should be established prior to orchard installation. When setting up training systems, attention should be paid to ensuring that they are both economically feasible and capable of supporting the plant canopy and fruit load. Globally, the most commonly used training systems in passiflora cultivation are the hedge (trellis) and T systems. In the hedge system, two wires are installed between the posts, with one wire positioned approximately 10 cm below the top of the posts and the second wire placed 70 cm below the first. In the commonly preferred T training system, posts are installed at a height of 1.5–2.0 m and spaced approximately 4 m apart. In this system, a 50 cm-long T shaped crossarm is mounted on each post, and three wires are installed (McCarthy & Dick, 1995). In Türkiye, the hedge system is the most widely used training system in passiflora cultivation; however, in some studies, the T system, modified T system, and Y system have also been applied. Balkıç (2022), investigated the effects of different training systems on the yield and quality of passiflora under open-field and protected cultivation conditions in Antalya and reported that each training system has its own advantages and disadvantages. The author emphasized that cultivation and training systems should be selected according to the intended production objectives.

Passiflora is classified among minor fruit crops worldwide (Altendorf, 2018). In Türkiye, interest in passiflora cultivation has begun to increase, as observed for other tropical fruit species. The growing interest in this crop is primarily attributed to its ease of propagation, ability to produce fruit twice a year, and early bearing shortly after planting. However, cultivation is generally not carried out on large-scale agricultural lands but is instead limited to small scale and hobby oriented production. In the Mediterranean and Aegean coastal regions, where tropical fruit cultivation is practiced, the most important limiting factors are the high cost of land and the preference for crop species that provide higher economic returns per unit area. Nevertheless, the widespread use of passiflora in the ice cream and pastry industries, as well as its preference by hotels operating within the tourism sector, demonstrates that passiflora is a high value-added fruit species with significant economic potential. In Türkiye, passiflora is cultivated as a main crop in only a few locations. Due to its climbing growth habit, this species is also commonly preferred as a hedge plant, particularly along fences installed at the borders of orchards or greenhouses (Figure 1).

a.

b.

Figure 1. General view of plants grown as hedge plants (a) and fruits (b).

Many tropical fruit species are imported into Türkiye, resulting in significant foreign exchange losses for the agricultural sector. Increasing domestic production of tropical fruit species that can be cultivated under local conditions would help reduce external dependency while simultaneously expanding product diversity within national agriculture. In this context, passiflora occupies a priority position among these species due to its favorable agronomic and commercial characteristics. In particular, if production increases beyond a certain level, passiflora has considerable potential for utilization in the juice industry and in various fruit blends, owing to its distinctive high aroma and flavor profile.

PRACTICES, AND FUTURE PERSPECTIVES IN TÜRKİYE

Passiflora can be rapidly propagated by cuttings, tissue culture, and seeds. The ease of propagation is one of the key factors contributing to the increasing interest in passiflora cultivation. Propagation by cuttings and tissue culture represents vegetative propagation methods, whereas seed propagation, which is also widely practiced in Türkiye, is a generative propagation method. In fruit species propagated by seeds, genetic segregation occurs, resulting in non-uniform plants and the absence of true to type fruit production. Although propagation by cuttings in passiflora is easy and can be widely applied, many growers prefer to produce seedlings from seeds extracted from harvested fruits and establish orchards using these seed derived plants. This practice leads to variability not only in fruit characteristics but also in the level of tolerance of plants to abiotic stress factors. Figure 2 illustrates the effects of low winter temperatures on plants in an orchard established from seed propagated passiflora in Serik/Antalya. Within the orchard, a large number of plants were observed to be affected by frost damage, whereas only a limited number of plants survived. These findings demonstrate that passiflora plants propagated from seeds may exhibit pronounced differences in physiological characteristics.

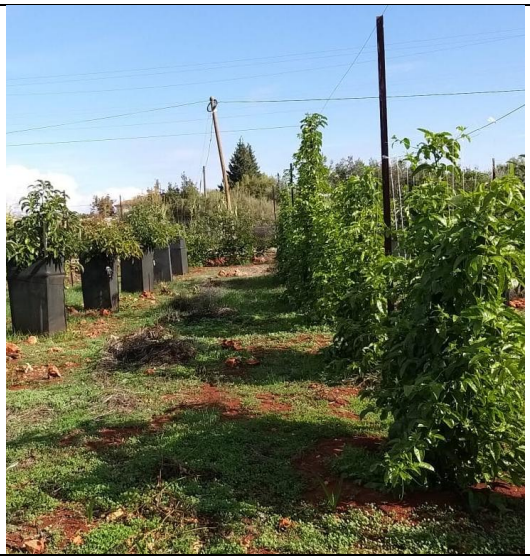
a. **b.**

Figure 2. General view of plants within the orchard showing frost-affected (a) and unaffected (b)individuals.

In Türkiye, passiflora cultivation is predominantly carried out under open-field conditions; however, protected cultivation practices are also applied. Protected passiflora cultivation offers an earlier production model compared to open-field conditions. In open-field cultivation, pollination and fertilization in passiflora, which has showy flowers, are generally achieved by insects, and no significant problems are encountered in this process. In contrast, under protected cultivation, limitations in natural pollinators may result in insufficient pollination and fertilization. This situation leads to significant reductions in fruit set and, consequently, yield. Therefore, in protected cultivation, the use of bumblebees or the application of manual pollination is required. In addition, high temperatures encountered during the summer period may adversely affect fruit quality. To prevent such negative effects, careful attention should be paid to seasonal climate control practices (such as shading and misting) and appropriate irrigation management in protected cultivation.

Since Passiflora is a plant with a climbing growth habit, the use of a support and training system is essential in its cultivation. As observed worldwide, the most commonly used training system in passiflora cultivation in Türkiye is the hedge (trellis) system. In addition, the pergola system and the T training system are also applied to a certain extent in Türkiye. Furthermore, passiflora is widely utilized in Türkiye not only as a main crop but also as a hedge plant. In particular, its cultivation as a hedge plant along wire-fenced orchard and field boundaries highlights the potential of this species to provide additional income alongside the main crop.

Passiflora has also begun to be considered as an intercrop in perennial fruit species that share similar ecological requirements and have a late bearing habit. In particular, the early bearing characteristic of passiflora allows it to be cultivated in combination with other fruit species. Avocado cultivation can be given as an example of this practice. Figure 3 illustrates the status of passiflora plants planted between avocado rows in 2021 and 2023. During the period until avocado plants reach economic yield, approximately 4–5 harvests can be obtained from passiflora plants, thereby covering a significant portion of the production costs.



a.

b.

Figure 3. Views of passiflora plants intercropped between avocado seedlings in 2021 (a) and 2023 (b).

Türkiye's climatic diversity and ecological advantages for subtropical fruit cultivation indicate a significant future potential for passiflora. The identification of suitable species and cultivars, particularly the expansion of adaptation studies focusing on *Passiflora edulis* Sims f. *edulis*, will play a key role in the widespread adoption of this crop. In addition, the integration of passiflora into fresh consumption markets, the food industry, and the tourism sector will further enhance its economic value. With the development of standardized seedling production, grower training programs, and strengthened marketing infrastructure, passiflora is considered to have the potential to become a high value-added alternative fruit species for Türkiye.

REFERENCES

Altendorf S. 2018. Minor tropical fruits. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Tropical_Fruits/Documents/Minor_Tropical_Fruits_FoodOutlook_1_2018.pdf

Balkıç, R. (2022). Farklı yetiştirme ve terbiye sistemlerinin passiflora (*Passiflora* L.)'da büyüme-gelişme, verim ve kalite üzerine etkileri. Doktora Tezi, Akdeniz Üniversitesi, Fen Bilimleri Enstitüsü, Antalya. 104s.

Feuillet, C., & MacDougal, J. M. 2007. Passifloraceae. In Kubitzki K. (Ed.), Flowering Plants Eudicots. The Families and Genera of Vascular Plants (Vol. 9, pp. 270–281). Springer.

Fonseca, A.M., Geraldi, M.V., Junior, M.R.M., Silvestre, A.J., & Rocha, S.M. 2022. Purple passion fruit (*Passiflora edulis* f. *edulis*): A comprehensive review on the nutritional value, phytochemical profile and associated health effects. Food Research International, 160, 111665.

Gübbük H., Biner, B., Dal, B., Yıldırım, I., Taşgın, D. ve Buhur, L. 2017. Değişik tropik meyve türlerinin Antalya koşullarına adaptasyonu üzerinde araştırmalar. Antalya Valiliği, Antalya. 83 s.

Li, H., Zhou, P., Yang, Q., Shen, Y., Deng, J., Li, L., & Zhao, D. (2011). Comparative studies on anxiolytic activities and flavonoid compositions of Passiflora edulis 'edulis' and Passiflora edulis 'flavicarpa'. Journal of ethnopharmacology, *133*(3), 1085-1090.

Mc Carthy A. and Dick J. 1995. Passion fruit culture. Government of Western Australia, Department of Agriculture, Farmnote, (51): 1-4

Schotsmans, W.C., & Fischer, G. 2011. Passion fruit (*Passiflora edulis* Sim.). In E. M. Yahia (Ed.), Postharvest Biology and Technology of Tropical and Subtropical Fruits (Vol. 4, pp. 125–143e). Woodhead Publishing.

EFFECTS OF IBA SOLUTIONS PREPARED WITH DIFFERENT ALCOHOL CONCENTRATIONS ON ROOTING IN PASSIFLORA EDULİS

Recep BALKIÇ

Akdeniz University, Elmalı Vocational School, Department of Plant and Animal Production, Antalya, Turkey

ORCID ID: https://orcid.org/0000-0002-1212-9501

Lokman ALTINKAYA

Akdeniz University, Kumluca Vocational School, Department of Plant and Animal Production, Antalya, Turkey

ORCID ID: https://orcid.org/0000-0002-8163-2530

Hamide GÜBBÜK

Akdeniz University, Department of Horticulture, Faculty of Agriculture, Antalya, Turkey

ORCID ID: https://orcid.org/0000-0003-3199-0660

ABSTRACT

Passiflora is among the tropical fruit species whose commercial potential is rapidly increasing in Türkiye. Vegetative propagation by cuttings is widely used in seedling production, and rooting success may vary depending on the growth regulators applied and the methods used in their preparation. Scientific data on the effects of the alcohol concentration used in preparing Indole-3-butyric acid (IBA) solutions on hormone efficacy and on the treated cuttings are limited. This study aimed to determine the effects of preparing a 1000 ppm IBA solution with different alcohol concentrations (30%, 40%, and 50%) on the rooting performance of semi-hardwood cuttings of *Passiflora edulis*. In the study, semi-hardwood cuttings of the "Possum Purple" cultivar, each approximately 20 cm in length and containing at least three nodes, were used. In addition to the control treatment, three Indole-3-butyric acid (IBA) solutions prepared with different alcohol concentrations (30% alcohol + 70% water, 40% alcohol + 60% water, and 50% alcohol + 50% water) were applied. The experiment was designed with three replicates, each consisting of 10 cuttings, for a total of 120 cuttings. Perlite was used as the rooting medium. The trial was conducted over a period of 60 days in an unheated glass rooting greenhouse, where the misting system was set to operate for 15 seconds every hour. The rooting percentage showed clear differences among the treatments, with the highest value obtained from the control group (95.23%). This was followed by the 30% alcohol (70.00%) and 40% alcohol (53.33%) treatments. The 50% alcohol treatment produced the lowest rooting percentage (33.33%). Although the highest number of primary roots was recorded in the 50% alcohol treatment (20.4 roots), root quality and root thickness were reduced in this group. Average root length was highest in the control (12.95 cm) and 30% alcohol (12.92 cm) treatments. Root fresh and dry weights also varied among treatments. The control and 30% alcohol treatments exhibited the highest root fresh and dry weights, whereas increasing alcohol

concentrations caused a noticeable decline in these parameters. The findings indicate that the alcohol concentration used in preparing the IBA solution has a significant effect on rooting success. Although higher alcohol levels increased the number of roots in semi-hardwood cuttings, they negatively affected both the rooting percentage and overall root quality. The most balanced and horticulturally favorable results were obtained from the control and 30% alcohol treatments. This study provides practical insights for optimizing IBA preparation protocols in the propagation of *Passiflora edulis* seedlings.

Key Words: Propagation; Cutting; Passiflora; Rooting; Indole-3-butyric acid

INTRODUCTION

Interest in tropical fruit species has been increasing steadily in recent years. Fruit crops such as banana, mango, pineapple, and papaya, which have high production volumes, also account for substantial levels of international trade. In contrast, fruit species classified within the minor fruit group, including passion fruit, longan, litchi, and mangosteen, are produced in relatively smaller quantities and have more limited commercial circulation compared to major tropical fruits (Altendorf, 2018).

Within the minor fruit group, the genus Passiflora particularly *Passiflora edulis* is known to comprise more than 500 species (Cerqueira-Silva et al., 2018). Among these, purple passion fruit (*Passiflora edulis* f. *edulis* Sims), yellow passion fruit (*Passiflora edulis* f. flavicarpa), and granadilla (*Passiflora quadrangularis* L.) are the most widely cultivated species (Balkıç, 2022). With respect to utilization patterns, yellow passion fruit is predominantly preferred for processing purposes, whereas purple passion fruit is commonly consumed fresh in addition to its use in processed products (Deshmukh et al., 2017).

The first official scientific study aimed at evaluating the adaptation of tropical fruit species to the ecological conditions of Türkiye was conducted through a collaborative effort involving the Antalya Provincial Directorate of Agriculture and Forestry, the West Mediterranean Agricultural Research Institute, and the Faculty of Agriculture at Akdeniz University. Within the scope of this project, adaptation trials were initiated in 2012 in the Alanya and Gazipaşa districts of Antalya for several tropical fruit species, including passion fruit, guava, mango, longan, litchi, and pitaya (Gübbük, 2017). Among these species, passion fruit and pitaya emerged as particularly promising crops, and their cultivation has increased progressively in recent years. Under Türkiye growing conditions, the ability of passion fruit to flower and bear fruit twice a year, its ease of propagation, and its early onset of fruiting after planting have played a significant role in the expansion of its cultivation.

Passiflora species can be readily propagated vegetatively through stem cuttings; however, propagation by seed and tissue culture is also possible. Among vegetative propagation methods, cutting propagation is widely practiced, and plant growth regulators are frequently used to stimulate adventitious root formation. Studies conducted in this context have reported that both the rooting substrate and the type of growth regulator applied play a decisive role in rooting success.

Boboc et al. (2020) investigated the effects of different rooting substrates and biostimulant applications on the rooting performance of stem cuttings of *Passiflora caerulea* and *P. quadrangularis*. Their results indicated that cuttings treated with 1000 ppm indole-3-butyric acid (IBA) and rooted in vermiculite achieved the highest rooting percentage (74.47%). Similarly, Bemkaireima et al. (2012) evaluated the effects of different node numbers (two-, three-, and four-node cuttings) and IBA concentrations (250, 500, 750, and 1000 ppm) on the rooting of purple passion fruit (*Passiflora edulis* var. *edulis* Sims) under Manipur (India)

conditions. Based on all evaluated parameters, the authors concluded that 750 ppm IBA was the most effective concentration for promoting rooting. In another study conducted in India, Parse et al. (2018) examined the effects of indole-3-butyric acid (IBA), naphthaleneacetic acid (NAA), salicylic acid, and ethanol applications on the rooting success of passion fruit cuttings. The results demonstrated that, compared to the control treatment, 1000 ppm IBA produced the most favorable outcomes with respect to both root and shoot growth parameters. Under Turkiye conditions, Uzunoğlu & Mavi (2016), evaluated the rooting performance of *Passiflora caerulea* cuttings grown in a pumice substrate under different IBA concentrations (500, 1000, 2000, and 3000 ppm). Measurements taken 45 days after planting revealed that the highest rooting percentage, root number, root length, and callus formation rate were obtained with the 1000 ppm IBA treatment.

In recent years, the use of biologically based inputs, in addition to growth regulators, has gained increasing attention in the rooting of passion fruit cuttings. Altınkaya et al. (2024) investigated the effects of different rooting substrates (perlite and vermiculite) and biostimulant applications on the rooting performance of the passion fruit cultivar 'Possum Purple' under Antalya (Türkiye) conditions. In this study, biostimulant treatments included IBA and a microbial fertilizer commercially known as Best-doll, applied either alone or in combination with IBA. The microbial fertilizer contained *Penicillium bilaii*, *Bacillus megaterium*, *Azospirillum brasilense*, *Arthrobacter viscosus*, *Azotobacter vinelandii*, *Azotobacter chroococcum*, and *Pseudomonas* spp., with a total microbial density of 2×10^7 cfu mL^{-1}. The results indicated that the highest rooting percentages were obtained in the control, microbial fertilizer, and microbial fertilizer + 750 ppm IBA treatments.

As outlined above, numerous studies have investigated the rooting of passion fruit cuttings. While these studies have consistently reported the positive effects of different IBA concentrations on rooting performance, the proportion of alcohol and distilled water used in the preparation of IBA solutions has generally not been specified. Passion fruit cuttings are semi-hardwood in nature, and it is therefore presumed that high alcohol concentrations in IBA solutions may cause damage to living tissues, potentially impairing rooting success. For these reasons, the present study was designed to evaluate the effects of IBA solutions prepared with different alcohol concentrations on the rooting performance of the passion fruit cultivar 'Possum Purple'.

MATERIALS AND METHODS

This study was conducted between 2019 and 2020 in the glass mist-propagation greenhouse located at the Research and Experimental Fields of the Faculty of Agriculture, Akdeniz University. In the experiment, 3 nodes semi-hardwood cuttings of the passion fruit cultivar 'Possum Purple' (*Passiflora edulis* f. *edulis*) were used. Except for the control treatment, prepared cuttings were treated for 10 seconds with 1000 ppm IBA solutions prepared using three different alcohol concentrations. For the preparation of IBA solutions, three separate batches were prepared by dissolving 0.1 g of pure IBA, weighed using a precision balance, in different volumes of absolute ethyl alcohol, followed by dilution with distilled water to a final volume of 100 ml. The treatments were as follows:

1. Control (distilled water only)
2. 1000 ppm IBA (30 ml absolute ethyl alcohol + 70 ml distilled water)
3. 1000 ppm IBA (40 ml absolute ethyl alcohol + 60 ml distilled water)
4. 1000 ppm IBA (50 ml absolute ethyl alcohol + 50 ml distilled water)

After treatment, the cuttings were planted in trays filled with perlite, placed under an intermittent misting system, with a spacing of 5 cm within rows and 10 cm between rows. The cuttings were allowed to root for 60 days, and the misting system was programmed to operate for 15 seconds every hour.

At the end of the rooting period, the following parameters were evaluated in the rooted cuttings:

Rooting percentage (%): Calculated as the ratio of rooted cuttings to the total number of cuttings and expressed as a percentage.

Primary roots number (count.): Determined by counting the number of primary roots formed on each rooted cutting.

Average root diameter (mm): The diameter of five randomly selected roots from each rooted cutting was measured near the root collar, and the mean value was calculated.

Average root length (cm): The length of five randomly selected roots from each rooted cutting was measured, and the mean value was calculated.

Longest root length (cm): Determined by measuring the length of the longest root on each rooted cutting.

Fresh root weight (g): Roots were excised at the root collar and weighed using a precision balance to determine fresh weight.

Fresh Leaf weight (g): Leaves were detached from rooted cuttings and weighed using a precision balance to determine fresh weight.

Dry root weight (g): Roots excised at the root collar were oven-dried at 65 °C until constant weight was achieved, after which dry weights were recorded.

Dry leaf weight (g): Leaves detached from rooted cuttings were oven-dried at 65 °C until constant weight was achieved, and final dry weights were recorded.

The experiment was arranged with three replications, each consisting of 10 cuttings, resulting in a total of 120 cuttings. All data obtained were subjected to analysis of variance (ANOVA) using the XLSTAT statistical software. Mean comparisons were performed using the least significant difference (LSD) test. In addition, principal component analysis (PCA) was conducted to evaluate the relationships among the measured variables, also using the XLSTAT program.

RESULT AND DISCUSSION

The effects of IBA solutions prepared with different alcohol concentrations on rooting percentage, number of primary roots, average root diameter, average root length, and longest root length in passion fruit cuttings are presented in Table 1. With respect to rooting percentage, the highest rooting rate (95.24%) was recorded in the control treatment, followed by the IBA solution prepared with 30% alcohol (70.00%), 40% alcohol (53.33%), and 50% alcohol (33.33%), respectively. In contrast, the number of primary roots exhibited an inverse relationship with rooting percentage, as clearly shown in Table 1. Accordingly, the highest number of primary roots (20.42) was observed in the treatment with IBA prepared using 50% alcohol, which also resulted in the lowest rooting percentage.

Table 1. The effects of IBA prepared with different alcohol concentrations on rooting rate, primary root number, average root diameter, average and maximum root length in Passiflora.

Treatment	Rooting Percentage (%)	Primary Root Number (count)	Average Root Diameter (mm)	Average Root Length (cm)	Longest Root Length (cm)
Control	95.24 a*	10.57 b	1.22 a	11.11 b	25.26 b
IBA (%30 Alc.)	70.00 b	19.85 a	0.95 b	13.35 a	17.47 a
IBA (%40 Alc.)	53.33 c	19.00 a	0.88 c	8.95 c	14.22 b
IBA (%50 Alc.)	33.33 d	20.42 a	0.80 d	11.99 ab	15.05 b
LSD%5	10.928	1.863	0.048	1.415	1.594

*: (P<0.05)

The lowest number of primary roots (10.57 roots per cutting) was recorded in the control treatment. The highest average root diameter was observed in the control treatment (1.22 mm), whereas the lowest root diameter (0.80 mm) was determined in the treatment with IBA prepared using 50% alcohol (Table 1). Both the average root length and the longest root length were highest in the treatment with IBA prepared using 30% alcohol (Table 1).

The effects of IBA solutions prepared with different alcohol concentrations on root fresh and dry weights as well as leaf fresh and dry weights of passion fruit cuttings are presented in Table 2. As shown in Table 2, IBA solutions prepared with different alcohol concentrations did not have a statistically significant effect on root fresh and dry weights, whereas their effects on leaf fresh and dry weights were significant. The highest leaf fresh weight (6.67 g) and leaf dry weight (1.75 g) were recorded in the control treatment, which also exhibited the highest rooting percentage. In contrast, the lowest leaf fresh weight (2.97 g) was observed in the treatment with IBA prepared using 40% alcohol. Additionally, the lowest leaf dry weight was recorded in the treatment with IBA prepared using 50% alcohol (Table 2).

Table 2. The effects of IBA prepared with different alcohol concentrations on root fresh/dry weight and leaf fresh/dry weight in Passiflora.

Treatment	Fresh Root Weight (g)	Dry Root Weight (g)	Fresh Leaf Weight (g)	Dry Leaf Weight (g)
Control	3.57	0.73	6.67 a	1.75 a
IBA (%30 Alc.)	4.05	0.71	4.23 b	1.01 b
IBA (%40 Alc.)	3.57	0.58	2.97 c	0.75 c
IBA (%50 Alc.)	3.76	0.50	3.29 c	0.72 c
LSD%5	N.S.**	N.S.	0.751	0.233

*: (P<0.05), **N.S.: Non Significant

The (PCA) performed on all obtained data is presented in Figure 1.

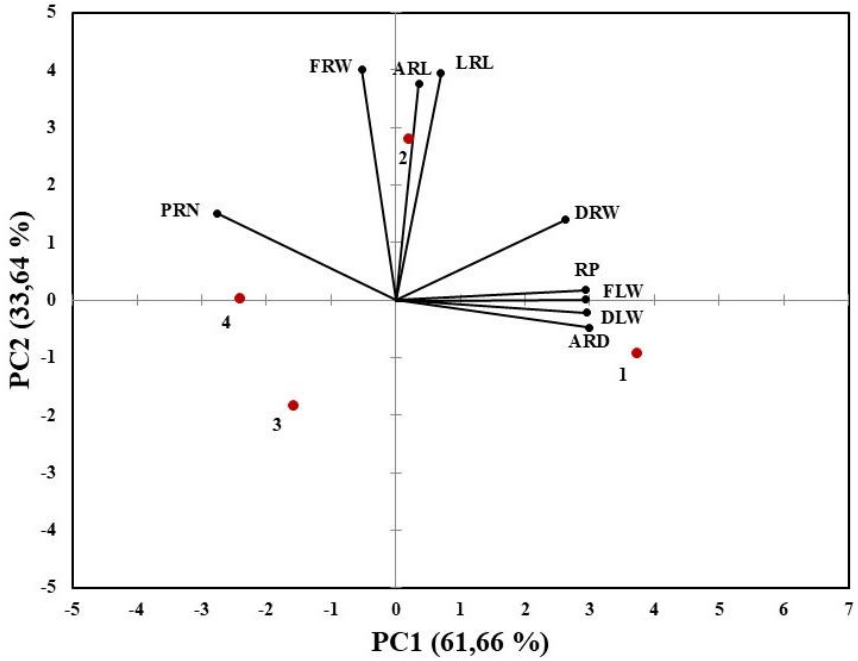


Figure 1. Biplot graph of rooting percentage (RP), primary root number (PRN), average root diameter (ARD), average (ARL) and longest root length (LRL), fresh (FRW) and dry root weight (DRW), and fresh (FLW) and dry leaf weight (DLW) in response to IBA treatments prepared with different alcohol concentrations. (1: Control, 2: IBA (%30 Alc.), 3: IBA (%40 Alc.), 4: IBA (%50 Alc.))

The principal component analysis (PCA) revealed that the first two components (PC1 and PC2) together explained 95.30% of the total variance. As illustrated in Figure 1, increasing the alcohol concentration used in the preparation of the IBA solution resulted in a decline in the evaluated parameters. Rooting percentage, root length, root diameter, and leaf fresh and dry weights were positively correlated with each other, whereas these parameters exhibited a negative correlation with the number of primary roots, as shown in Figure 2.

Numerous studies on the vegetative propagation of Passiflora species have reported that indole-3-butyric acid (IBA) applications enhance rooting success (Bemkaireima et al., 2012; Parse et al., 2018; Boboc et al., 2020; Uzunoğlu & Mavi, 2016). However, in the present study, the highest rooting percentage was obtained in the control treatment, while a marked decrease in rooting was observed with increasing alcohol concentration, indicating that semi-hardwood passion fruit cuttings are sensitive to high alcohol levels. In particular, the reduced rooting percentages observed in IBA solutions prepared with 40% and 50% alcohol suggest that alcohol may exert phytotoxic effects on living tissues. Although this finding appears to contrast with the high IBA efficiencies reported in the literature, the lack of detailed information regarding the solvent composition used in IBA solution preparation in most studies may represent a major reason for this discrepancy. Indeed, McCracken (1987), emphasized that the choice of solvent used in the preparation of auxin-based rooting hormones should be made with caution. This perspective supports the findings of the present study and highlights the importance of considering alternative solvents or lower alcohol concentrations when applying IBA, particularly in green and semi-hardwood cuttings. In this study, while the highest rooting percentage was recorded in the control treatment, the lowest rooting percentage was observed at the highest alcohol concentration. The results further revealed an inverse relationship between rooting percentage and the number of primary roots. Nevertheless, the reduction in primary root number was accompanied by increases in root diameter and root length, indicating

that fewer roots developed more robustly. As the number of primary roots decreased, individual roots became longer and thicker. This response is consistent with the findings of Hartmann et al. (2011), who reported that under conditions where a limited number of adventitious roots are formed, plants tend to allocate carbon resources to fewer roots, thereby promoting the development of thicker and longer roots. The higher leaf fresh and dry weights recorded in the control treatment further indicate that overall plant growth was healthier under conditions associated with higher rooting percentages. These results are in agreement with the findings of Altınkaya et al. (2024), who demonstrated that alternative approaches beyond chemical applications can positively influence rooting success and seedling quality.

CONCLUSION

This study demonstrated the effects of IBA solutions prepared with different alcohol concentrations on the rooting success and root development of Passiflora edulis f. edulis 'Possum Purple' cuttings. The results showed that increasing alcohol concentration led to a marked reduction in rooting percentage, whereas decreases in root number were accompanied by increases in root diameter and length. High alcohol concentrations were found to exert phytotoxic effects on semi-hardwood passion fruit cuttings, thereby negatively affecting rooting performance. These findings indicate that the effectiveness of IBA in rooting is dependent not only on hormone concentration but also on the alcohol content of the solution. Therefore, careful optimization of the alcohol concentration used in the preparation of IBA solutions is recommended for the vegetative propagation of passion fruit.

REFERENCES

Altendorf S. 2018. Minor tropical fruits. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Tropical_Fruits/Documents/Minor_Tropical_Fruits_FoodOutlook_1_2018.pdf

Altınkaya, L., Gübbük, H., & Biner, B. (2024). Effect of microbial fertilizers and growth media on the rooting of passion fruit (cv. Possum Purple) cuttings. Indian Journal of Horticulture, *81*(1).

Balkıç, R. (2022). Farklı yetiştirme ve terbiye sistemlerinin passiflora (*Passiflora* L.)'da büyüme-gelişme, verim ve kalite üzerine etkileri. Doktora Tezi, Akdeniz Üniversitesi, Fen Bilimleri Enstitüsü, Antalya. 104s.

Bemkaireima, K., Angami, T., & Singh, M.S. (2012). Response of different size and growth regulator on cuttings of passion fruit var. Purple (*Passiflora edulis* var. *edulis* Sims). The Asian J. of Hort, *7*(2), 515-520.

Boboc, P., Catana, C., Gocan, T., Moldovan, G., Székely-Varga, Z., & Cantor, M. (2020). Influence of culture substrates and biostimulators on Passiflora rooting. Bulletin UASVM Horticulture, *77*(1), 12-18.

Cerqueira-Silva, C.B.M., Faleiro, F.G., Jesus, O.N.D., Santos, E.S.L.D. and Souza, A.P.D. 2018. Passion fruit (Passiflora spp.) breeding. In Al-Khayri, J., Jain, S., Johnson, D. (Eds.), Advances in plant breeding strategies: Fruits Springer, Cham pp. 929-951.

Deshmukh, N.A., Patel, R.K., Okram, S., Rymbai, H., Roy, S.S. and Jha, A.K. 2017. "Passion fruit (Passiflora spp.)". In: Ghosh, S. N., Singh, A., Thakur, A. (Eds.), Underutilized Fruit Crops: Importance and Cultivation. Jaya Publishing House, Delhi: 1420p.

Gübbük H., Biner, B., Dal, B., Yıldırım, I., Taşgın, D. ve Buhur, L. 2017. Değişik tropik meyve türlerinin Antalya koşullarına adaptasyonu üzerinde araştırmalar. Antalya Valiliği, Antalya. 83 s.

Hartmann, H.T., Kester, D.E., Davies, F.T., & Geneve, R.L. (2011). Plant propagation: Principles and practices (8th ed.). Prentice Hall.

McCracken, T.P. (1987). Effect of alcohol solvents and IBA on rooting of select woody ornamental and herbaceous plants. Master Theses. University of Tennessee

https://trace.tennessee.edu/utk_gradthes/7313/

Parse, R.N., Mane, S.B., & Nag, U.M. (2018). Effect of different chemicals on root growth success of cuttings in passion fruit. International Journal of Current Microbiology and Applied Sciences, *7*(9), 3139-3144.

Uzunoğlu, F., & Mavi, K. (2016). Çarkıfelek (*Passiflora caerulea* L.) türünde indol bütirik asit uygulamalarının çelik köklenmesi üzerine etkisi. Bahçe, *45*(Özel Sayı 1) 7. Ulusal Bahçe Bitkileri Kongresi), 943-949.

USE OF CANONICAL CORRELATION ANALYSIS IN ASSESSING THE RELATIONSHIP BETWEEN BODY MEASUREMENTS AND CARCASE CHARACTERISTICS IN AWSSI SHEEP

İVESİ KOYUNLARINDA VÜCUT ÖLÇÜLERİ İLE KARKAS ÖZELLİKLERİ ARASINDAKİ İLİŞKİNİN DEĞERLENDİRİLMESİNDE KANONİK KORELASYON ANALİZİNİN KULLANILMASI

Prof. Dr. Ömer Cevdet BİLGİN

Atatürk Üniversitesi, Fen Fakültesi

Prof. Dr. Nurinisa ESENBUĞA

Atatürk Üniversitesi, Ziraat Fakültesi

ÖZET

Koyunlarda morfometrik ölçüler ile karkas verimi arasındaki ilişkinin doğru şekilde belirlenmesi, besi yönetimi, seleksiyon stratejileri ve verim tahminlerinin geliştirilmesi açısından büyük önem taşımaktadır. Bu çalışmada, İvesi ırkı erkek kuzularda çeşitli ağırlık ve vücut ölçüleri ile karkas ağırlık ve ölçüleri arasındaki ilişkinin incelenmesi ve karkas ağırlığı ve ölçülerini en iyi açıklayan morfometrik özelliklerin belirlenmesi amaçlanmıştır. Araştırmada temel yöntem olarak kanonik korelasyon analizi kullanılmıştır. Çalışmanın hayvan materyalini 15 baş İvesi erkek kuzusu oluşturmuştur. Kuzulardan kesimden önce alınan 6 adet vücut ölçüsü ile kesimden sonra alınan karkas ağırlık ve ölçüm verileri analizlerde kullanılmıştır. Canlı vücut ölçüleri ile karkas verileri arasındaki çok değişkenli ilişkileri ortaya koymak amacıyla kanonik korelasyon analizi (CCA) uygulanmış; ayrıca kanonik yükler, standart kanonik katsayılar ve çapraz yükler hesaplanmıştır. Analiz sonuçlarının desteklenmesi amacıyla ikili korelasyonlar değerlendirilmiş ve yorumlamada birinci kanonik varyete çifti dikkate alınmıştır. İlk kanonik varyete çifti için kanonik korelasyon katsayısı 0,97 olarak bulunmuş ve vücut ölçüleri ile soğuk karkas ağırlığı arasında yüksek düzeyde bir ilişki saptanmıştır. Bu varyeteyle karkas ağırlığındaki varyansın yaklaşık %90'ı, vücut ölçülerindeki varyansın ise %60'ı açıklanmıştır. Kanonik yükler incelendiğinde but çevresi, omuz yüksekliği ve göğüs derinliğinin vücut ölçüleri setine en fazla katkı sağlayan özellikler olduğu görülmüştür. Elde edilen bulgular, İvesi kuzularında canlı dönemde kolayca ölçülebilen bazı morfometrik özelliklerin soğuk karkas ağırlığını yüksek doğrulukla tahmin edebildiğini ortaya koymuştur. Özellikle but çevresi, omuz yüksekliği ve göğüs derinliği, karkas verimini belirleyen temel fenotipik göstergeler olarak öne çıkmaktadır. Örnek sayısının sınırlılığı istatistiksel anlamlılığı kısıtlasa da, kanonik korelasyonun yüksekliği pratik önem taşımaktadır. Sonuç olarak, İvesi koyunlarında karkas veriminin erken dönemde tahmin edilmesinde vücut ölçülerinin etkili bir kriter olarak kullanılabileceği belirlenmiştir.

Anahtar kelimeler: İvesi koyunu, Vücut ölçüleri, Karkas ölçüleri, Kanonik korelasyon

ABSTRACT

Accurately determining the relationship between morphometric measurements and carcass yield in sheep is crucial for improving livestock management, selection strategies, and yield predictions. This study aimed to investigate the relationship between various weight and body measurements and carcass weight and measurements in Awassi male lambs and to identify the morphometric traits that best explain carcass weight and measurements. Canonical correlation analysis was used as the primary method in the study. The animal material for the study consisted of 15 Awassi male lambs. Six pre-slaughter body measurements and post-slaughter carcass weight and measurement data were used in the analyses. Canonical correlation analysis (CCA) was applied to reveal multivariate relationships between live body measurements and carcass data; canonical loadings, standard canonical coefficients, and cross-loadings were also calculated. Pairwise correlations were evaluated to support the analysis results, and the first canonical variety pair was considered in the interpretation. The canonical correlation coefficient for the first canonical variety pair was 0.95, indicating a strong relationship between body measurements and cold carcass weight. This variety explained approximately 90% of the variance in carcass weight and 60% of the variance in body measurements. Examining the canonical loadings revealed that leg circumference, shoulder height, and chest depth contributed most to the set of body measurements. The findings revealed that some morphometric traits, easily measured at live age in Awassi lambs, can predict cold carcass weight with high accuracy. Leg circumference, shoulder height, and chest depth, in particular, stood out as key phenotypic indicators of carcass yield. While the limited sample size limits statistical significance, the high canonical correlation is of practical importance. In conclusion, body measurements can be used as an effective criterion for early-stage carcass yield prediction in Awassi sheep.

Key Words: Awassi sheep, Body measurements, Carcass measurements, Canonical correlation

GİRİŞ

Koyun yetiştiriciliğinde karkas verimi ve karkasın yapısal özellikleri, ekonomik değeri belirleyen en önemli unsurlar arasında yer almaktadır. Ancak karkas özelliklerinin doğrudan ölçülmesi yalnızca kesim sonrasında mümkün olduğundan, kesim öncesi dönemde kolay ve düşük maliyetle elde edilebilen canlı vücut ölçülerinin karkas verimiyle olan ilişkilerinin ortaya konulması büyük önem taşımaktadır (Bilgin ve Esenbuğa, 2009). Bu bağlamda, canlı morfometrik ölçülerin karkas özelliklerini ne ölçüde yansıtabildiğinin belirlenmesi, seleksiyon kararlarının desteklenmesi ve besi–kesim planlamasının daha etkin biçimde yapılabilmesi açısından önemli bir yaklaşım sunmaktadır. Canlı ağırlık, vücut uzunluğu, sağrı ve ekstremiteye ait ölçüler gibi temel morfometrik özelliklerin, koyunlarda büyüme performansı ve karkas verimiyle yakından ilişkili olduğu daha önce yapılan birçok çalışmada ortaya konulmuştur. Özellikle canlı ağırlık ve göğüs çevresi gibi ölçülerin, karkas ağırlığının güvenilir göstergeleri olduğu bildirilmektedir (Atta and El Khidir, 2004; Shehata, 2013). Benzer şekilde, farklı koyun ırklarında yapılan çalışmalarda canlı vücut ölçüleri ile karkas özellikleri arasında anlamlı ve güçlü ilişkiler saptanmış, bu ölçülerin karkas tahmininde kullanılabileceği vurgulanmıştır (Bautista-Díaz et al., 2020; Gomes et al., 2021).

Canlı ölçümler ile karkas özellikleri arasındaki ilişkilerin değerlendirilmesinde klasik tek değişkenli yöntemler sınırlı kalabilmekte, bu nedenle çok sayıda değişkenin birlikte ele alınabildiği çok değişkenli istatistiksel yöntemlere ihtiyaç duyulmaktadır. Bu kapsamda, kanonik korelasyon analizi (CCA), iki farklı değişken seti arasındaki ilişki yapısını bütüncül biçimde ortaya koyabilen etkili bir yöntem olarak öne çıkmaktadır. Nitekim, koyunlarda kesim öncesi canlı ölçümler ile kesim sonrası karkas özellikleri arasındaki ilişkilerin

değerlendirilmesinde kanonik korelasyon analizinin başarıyla kullanıldığı çeşitli çalışmalar bulunmaktadır (Bilgin ve Esenbuğa, 2009; Cankaya et al., 2009; Roberto et al., 2024). Türkiye'de yerli koyun ırkları üzerinde yapılan çalışmalar, canlı vücut ölçülerinin karkas parça ağırlıkları ve karkas yapısı ile olan ilişkilerinin ortaya konulmasında kanonik korelasyon analizinin önemli avantajlar sunduğunu göstermektedir. Morkaraman kuzularında yürütülen çalışmalarda, canlı dönemde ölçülen bazı vücut özelliklerinin karkas parçalarını yüksek doğrulukla temsil edebildiği bildirilmiştir (Bilgin ve Esenbuğa, 2009). Bununla birlikte, farklı ırklarda ve yetiştirme koşullarında bu ilişkilerin yeniden değerlendirilmesi gerektiği de vurgulanmaktadır.

İvesi (Awassi) koyunu, Türkiye'nin özellikle Güneydoğu Anadolu Bölgesi'nde yaygın olarak yetiştirilen, et ve süt verimi bakımından önemli bir ırk olmasına rağmen, bu ırkta canlı vücut ölçüleri ile karkas özellikleri arasındaki ilişkilerin çok değişkenli yöntemlerle ele alındığı çalışma sayısı sınırlıdır. Bu nedenle, İvesi erkek kuzularında canlı dönemde ölçülen vücut ölçüleri ile kesim sonrası karkas özellikleri arasındaki ilişkinin kanonik korelasyon analizi ile ortaya konulması hem bilimsel literatüre katkı sağlamak hem de uygulamaya dönük pratik sonuçlar üretmek açısından önem taşımaktadır (Bilgin et al. 2010).

Bu çalışmanın amacı, İvesi erkek kuzularında canlı dönemde ölçülen sınırlı sayıdaki vücut ölçüsü ile karkas verimi ve yapısını temsil eden temel karkas özellikleri arasındaki ilişkiyi kanonik korelasyon analizi kullanarak değerlendirmek ve karkas potansiyelini en iyi yansıtan canlı morfometrik ölçüleri belirlemektir.

MATERYAL ve METOD

Hayvan Materyali

Araştırmanın hayvan materyalini, aynı işletme koşullarında yetiştirilen toplam 15 baş İvesi erkek kuzusu oluşturmuştur. Kuzular yaklaşık olarak benzer yaş ve besi döneminde olup, çalışma kapsamındaki tüm ölçümler aynı bireylerden elde edilmiştir. Ölçümler, kesim öncesi canlı dönemde ve kesim sonrası karkas değerlendirmesi sırasında alınmıştır. Kesimden bir gün önce her bir kuzudan toplam 6 adet vücut ölçüsü alınmıştır. Ölçümler standart yöntemlere göre gerçekleştirilmiştir. Canlı ağırlık dijital hayvan tartısında, diğer vücut ölçüleri ise cetvel ve ölçü çubuğu kullanılarak elde edilmiştir. Ölçülen morfometrik özellikler şunlardır: Canlı ağırlık (kg), vücut uzunluğu (cm), arka dirsek yüksekliği (cm), incik çevresi (cm), son sağrı genişliği (cm), alın uzunluğu (cm). Kesim sonrası karkaslar 24 saat boyunca +4 °C'de soğutulmuş ve ardından toplam 6 karkas özelliği değerlendirilmiştir (Soğuk karkas ağırlığı (kg), karkas uzunluğu (cm), but iç uzunluğu (cm), but derinliği (cm), göğüs çevresi (cm), göğüs derinliği (cm)). Karkas ölçümleri, soğutulmuş karkas üzerinde, standart anatomik referans noktaları kullanılarak alınmıştır.

Kanonik Korelasyon Analizi (CCA): Canlı vücut ölçüleri (X seti) ve karkas parametreleri (Y seti) analiz öncesinde aşağıdaki adımlarla işlenmiştir: Eksik veri kontrolü yapılmış ve tüm bireylerde tam veri seti bulunduğu doğrulanmıştır. Tüm değişkenler ortalaması 0, varyansı 1 olacak şekilde standartlaştırılmıştır. Aykırı değer analizi yapılmış ve belirgin bir uç değer gözlenmemiştir. Vücut ölçüleri ile karkas özellikleri arasında çok değişkenli doğrusal ilişki yapısını belirlemek için Kanonik Korelasyon Analizi uygulanmıştır. CCA, X ve Y değişken setleri için aşağıdaki fonksiyonlar oluşturulmuştur (Tabachnick & Fidell 2013; Härdle & Simar 2015):

$$U = a_1X_1 + a_2X_2 + \ldots + a_pX_p$$
$$V = b_1Y_1 + b_2Y_2 + \ldots + b_qY_q$$

Burada U ve V, iki veri seti arasındaki maksimum korelasyonu temsil eden kanonik değişkenlerdir. Analizde: p = 6 (vücut ölçüleri), q = 6 (karkas ölçüleri), n = 15 (birey sayısı) olacak şekilde kanonik varyete çiftleri değerlendirilmiştir. CCA kapsamında şu istatistikler hesaplanmıştır: Kanonik korelasyon katsayısı, standart kanonik katsayılar, kanonik yükler ve açıklanan varyans oranları. Tüm analizler SAS paket programı kullanılarak gerçekleştirilmiştir.

BULGULAR ve TARTIŞMA

İvesi koyunlarında iki değişken grubuna ait ortalama ve standart sapmalar Çizelge 1'de sunulmuştur. İvesi erkek kuzularında kesimden önce ölçülen altı temel vücut ölçüsü ile kesim sonrası belirlenen altı karkas özelliği arasındaki ilişki yapısı kanonik korelasyon analizi ile incelenmiştir (Tablo 2). Analiz sonucunda birinci kanonik değişken çifti (U_1–V_1) için elde edilen yüksek kanonik korelasyon katsayısı (RC = 0.985), canlı morfometrik yapı ile karkas özellikleri arasında çok güçlü bir doğrusal ilişki bulunduğunu ortaya koymuştur (Tablo 2). İlk kanonik değişken çifti, iki değişken seti arasındaki ortak varyansın %97'sini açıklamış olup, indirgenme indeksinin yüksek olması canlı vücut ölçülerinin karkas özelliklerini yüksek doğrulukla temsil edebildiğini göstermektedir. Benzer şekilde, koyunlarda canlı ölçümler ile karkas özellikleri arasındaki ilişkilerin çok değişkenli yöntemlerle ele alındığı çalışmalarda ilk kanonik fonksiyonun yüksek açıklama gücüne sahip olduğu bildirilmektedir (Bilgin ve Esenbuğa, 2009; Cankaya et al., 2009; Kunene et al., 2009; Roberto et al., 2024).

Tablo 1. Araştırmada kullanılan değişkenlerin ortalama ve standart sapmaları

Bağımsız değişkenler	$\overline{X}$	$S_{\overline{x}}$	*Bağımlı değişkenler*	$\overline{X}$	$S_{\overline{x}}$
Canlı ağırlık (CA)	59.17	2.00	Soğuk karkas ağırlığı (SKA)	26.99	1.16
Vücut uzunluğu (VU)	74.47	3.74	Karkas uzunluğu (KU)	61.67	1.73
Arka dirsek yüksekliği (ADY)	22.73	1.90	But iç uzunluğu (BIU)	20.82	2.55
İncik çevresi (IN)	16.47	1.56	But derinliği (BD)	20.19	6.86
Alın uzunluğu (AU)	8.00	0.93	Göğüs derinliği (GD)	20.37	1.00
Son sağrı genişliği (SSG)	24.23	1.35	Göğüs çevresi (GÇ)	79.37	3.64

Canlı ölçümlerden oluşturulan U_1 kanonik değişkeninin yapısı incelendiğinde, son sağrı genişliği, incik çevresi ve canlı ağırlığın, karkasla ilişkili morfolojik profili en güçlü biçimde temsil eden değişkenler olduğu belirlenmiştir. Bu değişkenlerin hem kanonik ağırlıklarının hem de kanonik yüklerinin yüksek olması, arka vücut gelişimini yansıtan ölçümlerin karkas verimi açısından belirleyici olduğunu göstermektedir. Canlı ağırlık ve vücut uzunluğu da U_1 değişkeninde anlamlı yükler sergileyerek, genel beden büyüklüğünün karkasın kütlesel ve yapısal özellikleriyle bütüncül bir ilişki içinde olduğunu desteklemiştir. Arka vücut ve ekstremiteye ait ölçülerin öne çıkması, karkasın et verimi bakımından en değerli bölgesi olan but gelişimiyle biyolojik olarak uyumlu bir sonuçtur. Nitekim literatürde sağrı genişliği, bacak çevresi ve canlı ağırlık gibi ölçülerin karkas ağırlığı ve but gelişimiyle güçlü ilişkiler gösterdiği bildirilmektedir (Atta and El Khidir, 2004; Shehata, 2013; Bautista-Díaz et al., 2020; Atac and Altincekic, 2023).

Tablo 2. Canlı vücut ölçüleri ve karkas ölçüleri arasındaki Kanonik Korelasyon Analizinin özet sonuçları

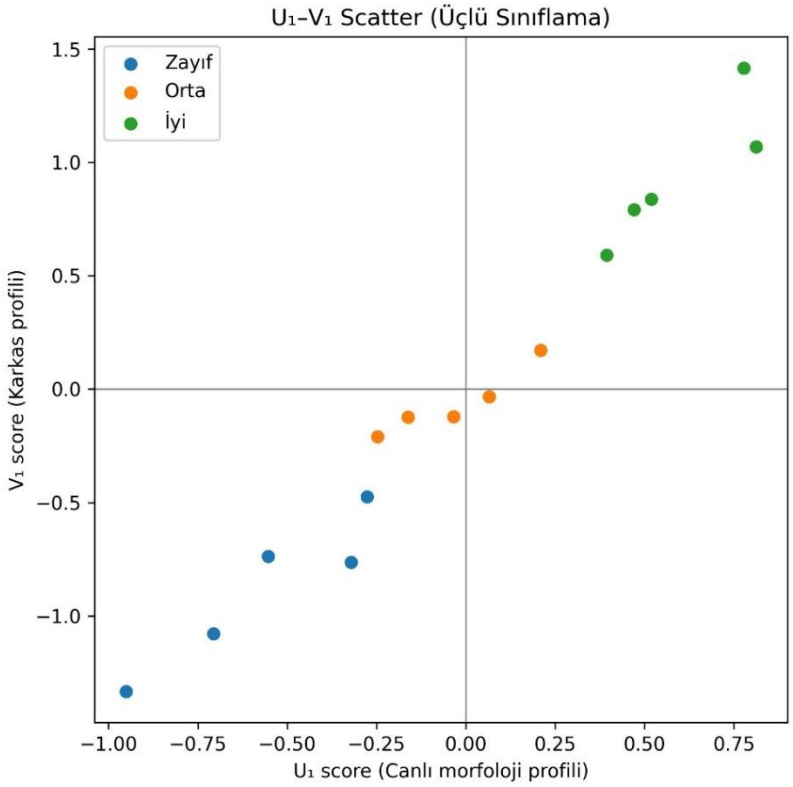
Kanonik Değişken Çiftleri	Kanonik Korelasyon (R_C)	Kanonik Korelasyonun Karesi (R_C^2)	F	Önemlilik Durumu	Olabilirlik Oranı (likelihood ratio)	İndirgenme İndeksi
$U_1 – V_1$	0.985	0.970	7.16*	0.341	0.030	0.970
$U_2 – V_2$	0.860	0740	2.57	0.742	0.260	0.740
$U_3 – V_3$	0.742	0.550	2.63	0.852	0.450	0.550
$U_4 – V_4$	0.662	0.439	2.35	0.523	0.561	0.439
$U_5 – V_5$	0.478	0.229	2.75	0.684	0.771	0.229
$U_6 – V_6$	0.099	0.01	2.54	0.984	0.990	0.01

Karkas ölçümleri setinde ise soğuk karkas ağırlığı, karkas uzunluğu ve göğüs çevresi, V_1 kanonik değişkeninin oluşumunda en yüksek kanonik yük ve ağırlıklara sahip değişkenler olarak öne çıkmaktadır. Bu bulgu, karkasın hem kütlesel (ağırlık) hem de boyutsal (uzunluk ve çevre ölçüleri) özelliklerinin canlı dönemdeki morfolojik yapı ile birlikte şekillendiğini göstermektedir. Karkas uzunluğu ve göğüs çevresinin yüksek yükler sergilemesi, bu ölçülerin karkas kompozisyonu ve kas dağılımını yansıtan temel göstergeler olduğunu ortaya koymaktadır. Benzer sonuçlar, farklı koyun ırklarında yapılan çalışmalarda da rapor edilmektedir (Gomes et al., 2021; Roberto al., 2024).

Tablo 3. Canlı vücut ölçüleri ve karkas ölçüleri icin hesaplanan standize edilmiş kanonik ağırlıklar ve yükler

Bağımsız değ.	Ağırlıklar	Yükler	Bağımlı değ.	Ağırlıklar	Yükler
CA	0.128	0.351	SKA	0.530	0.472
VU	-0.047	0.023	KU	-0.470	-0.671
ADY	-0.196	-0.425	BIU	-0.446	0.159
IN	0.521	0.211	BD	-0.153	-0.321
AU	0.457	0.278	GD	-0.523	-0.511
SSG	0.680	0.243	GÇ	0.054	0.057

Kanonik ağırlıklar ve kanonik yükler birlikte değerlendirildiğinde, canlı ölçümlerin kanonik değişkenin matematiksel yapısına katkısı ile biyolojik yorum gücü arasındaki fark daha net biçimde ortaya çıkmaktadır. Bu çalışmada, özellikle son sağrı genişliği ve incik çevresinin hem yüksek ağırlık hem de yüksek yük değerleri göstermesi, bu ölçümlerin karkasla ilişkili morfolojik yapıyı temsil etmede istatistiksel olarak güçlü ve biyolojik olarak anlamlı göstergeler olduğunu düşündürmektedir. Literatürde, kanonik ağırlıkların değişkenlerin modele katkısını, kanonik yüklerin ise biyolojik yorumu daha güvenilir biçimde yansıttığı vurgulanmakta olup, bu çalışmada elde edilen sonuçlar söz konusu yaklaşımı destekler niteliktedir (Salako, 2006; Yakubu and Ibrahim, 2011).



Grafik 1. Canlı vücut ölçülerinden elde edilen U_1 skorları ile karkas özelliklerinden elde edilen V_1 skorları arasındaki ilişki

U_1 ve V_1 skorları kullanılarak yapılan bireysel düzeyde değerlendirmede, kuzular İyi, Orta ve Zayıf olmak üzere üç gruba ayrılmışlardır. "İyi" grupta yer alan kuzuların hem pozitif U_1 hem de pozitif V_1 skorlarına sahip olduğu ve canlı morfolojik yapılarının karkas özellikleriyle yüksek düzeyde uyum gösterdiği belirlenmiştir. Buna karşılık, "Zayıf" gruptaki kuzuların her iki skor açısından da negatif değerlere sahip olduğu ve karkas potansiyelinin daha düşük olduğu görülmüştür. U_1–V_1 saçılım grafiğinde (Grafik 1) gruplar arasındaki belirgin ayrışma, kanonik skorların yalnızca teorik bir istatistiksel çıktı değil, aynı zamanda birey düzeyinde sınıflama ve karar destek aracı olarak da kullanılabileceğini göstermektedir. Benzer şekilde, kanonik skorların birey düzeyinde sınıflama ve seleksiyon amacıyla kullanılabileceği daha önce farklı hayvan materyallerinde de rapor edilmiştir (Bilgin ve Esenbuğa, 2009; Gomes et al., 2021; Roberto et al., 2024).

SONUÇ

Bu çalışmada, İvesi erkek kuzularında canlı dönemde ölçülen sınırlı sayıdaki vücut ölçüsünün karkas verimi ve yapısını ne ölçüde yansıtabileceği kanonik korelasyon analizi ile ortaya konulmuştur. Canlı vücut ölçüleri ile karkas özellikleri arasında çok güçlü bir ilişki bulunmuş, birinci kanonik değişken çifti iki değişken seti arasındaki ortak varyansın %97'sini açıklamıştır. Bu bulgu, canlı dönemde kolay ve düşük maliyetle elde edilebilen morfometrik ölçümlerin, kesim sonrası karkas özelliklerinin güvenilir birer göstergesi olabileceğini ortaya koymaktadır. Kanonik ağırlıklar ve yükler birlikte değerlendirildiğinde, özellikle son sağrı genişliği ve incik çevresinin, karkasla ilişkili yapıyı temsil etmede öne çıkan canlı ölçümler olduğu belirlenmiştir. Karkas tarafında ise soğuk karkas ağırlığı, karkas uzunluğu ve göğüs çevresi, karkasın hem kütlesel hem de yapısal gelişimini en iyi yansıtan özellikler olarak ön plana çıkmaktadır. Bu sonuçlar, arka vücut gelişimini temsil eden ölçülerin karkas verimi açısından kritik önem

taşıdığını ortaya koymaktadır. Ayrıca U1–V1 saçılım grafiğinde gruplar arasındaki belirgin ayrışma, kanonik skorların seleksiyon, besi planlaması ve karar destek süreçlerinde pratik bir araç olarak kullanılabileceğini göstermektedir. Sonuç olarak, İvesi erkek kuzularında sınırlı sayıda seçilmiş canlı vücut ölçüsüne dayalı kanonik korelasyon yaklaşımı, karkas verimi ve yapısının öngörülmesinde etkili, uygulanabilir ve saha koşullarına uygun bir yöntem sunmaktadır. Bu yaklaşımın, özellikle erken dönemde seleksiyon kararlarının desteklenmesi ve yetiştiricilikte verimliliğin artırılması açısından önemli katkılar sağlayabileceği düşünülmektedir.

KAYNAKLAR

Atac, F.E. & Altincekic, S.O. (2023). The relationship between live weight and body measurements in Chios lambs at different periods. *South African J. Anim. Sci*. 53(5).

Atta, M., & El Khidir, O.A. (2004). Use of heart girth, wither height and body length for prediction of live weight of Nilotic sheep. *Small Ruminant Research*, 55(1–3), 233–237.

Bilgin, O.C. & Esenbuga, N. (2009). Morkaraman kuzularının vücut ölçüleri ve karkas parça ağırlıkları arasındaki ilişkinin değerlendirilmesinde kanonik korelasyon analizinin kullanılması. *Atatürk Üniv. Ziraat Fak. Derg*. 40 (2), 1-10.

Bilgin, O.C., Esenbuga, N. & Davis, M.E. (2010). Comparison of models for describing the lactation curve of Awassi, Morkaraman and Tushin sheep. *Archiv. Anim. Breed*., 53(4), 447-456.

Bautista-Díaz, E., Mezo-Solis, J.A., Herrera-Camacho, J., Cruz-Hernández, A., Gomez-Vazquez, A., Tedeschi, L.O., Lee-Rangel, H.A., Vargas-Bello-Pérez, E. & Chay-Canul, A.J. (2020). Prediction of carcass traits of hair sheep lambs using body measurements. *Animals*, 10, 1276.

Cankaya, S., Altop, A., Olfaz, M. & Erener, G. (2009) Canonical correlation analysis for estimation of relationships between some traits measured at pre- and post-slaughtering periods in Karayaka hoggets. *Anadolu Journal of Agricultural Sciences*, 24, 61-66.

Gomes, M.B., Neves, M.L.M.W., Barreto, L.M.G., Ferreira, M.A., Monnerat, J.P.I.S., Carone, G.M., Morais, J.S. & Veras, A.S.C. (2021). Prediction of carcass composition through measurements in vivo and measurements of the carcass of growing Santa Inês sheep. *PLOS ONE*, 16(3), e0247950.

Härdle, W. K. & Simar, L. (2015). *Applied Multivariate Statistical Analysis* (4th ed.). Springer.

Kunene, N. W., Nesamvuni, A. E., & Fossey, A. (2009). Characterisation of Zulu (Nguni) sheep using linear body measurements and some environmental factors. *South African Journal of Animal Science*, 2007, 37 (1)

Shehata, M.F. (2013). Prediction of live body weight and carcass traits by some live body measurements in Barki lambs. *Egyptian Journal of Animal Production*, 50(2), 69–75.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using Multivariate Statistics* (6th ed.). Boston, MA: Pearson.

Roberto, F.F.S., Ribeiro, N.L., Difante G.S., Guidolin, D.G.F, Ítavo, L.C.V., Ítavo, C.C.B.F., Rodrigues, J.G., Pereira, M.G. & Costa, R.G. (2024). Using multivariate analysis to predict carcass characteristics of lambs in grazing and supplemented with different levels of non-protein nitrogen. *The Journal of Agricultural Science* 162, 275–282.

Salako, A.E. (2006). Application of morphological indices in the assessment of type and function in sheep. *International Journal of Morphology*, 24(1), 13–18.

Yakubu, A., & Ibrahim, I.A. (2011). Multivariate analysis of morphostructural characteristics in Nigerian indigenous sheep. *Italian Journal of Animal Science*, 10, e17.

COMPARISON OF LACTATION CURVE MODELS IN TUJ SHEEP

TUJ KOYUNLARINDA LAKTASYON EĞRİSİ MODELLERİNİN KARŞILAŞTIRILMASI

Prof. Dr. Nurinisa ESENBUĞA

Atatürk Üniversitesi, Ziraat Fakültesi

ORCID NO: 0000-0002-2036-8369

Prof. Dr. Ömer Cevdet BILGIN

Atatürk Üniversitesi, Fen Fakültesi,

ORCID NO: 0000-0003-3805-3848

ÖZET

Laktasyon eğrilerinin doğru modellenmesi, koyunlarda süt veriminin yönetimi, ıslah planlaması ve verim tahminlerinin güvenilir şekilde yapılabilmesi açısından büyük önem taşımaktadır. Bu çalışmada, Tuj koyunlarının 3–27. haftalar arasında ölçülen süt verimlerine dört farklı matematiksel modelin uygulanması, modellerin tahmin performanslarının karşılaştırılması ve Tuj koyunlarının laktasyon eğrisini en iyi temsil eden modelin belirlenmesi amaçlanmıştır. Çalışmanın hayvan materyalini 31 baş Tuj koyunu oluşturmuştur. Tuj koyunlarının laktasyon eğrileri Wood (WD), Cobby and Le Du (CD), Morant and Gnanasakthy (MG) ve Gipson and Grossman (GG) modelleri kullanılarak değerlendirilmiştir. Karşılaştırmalar MSPE, R^2 ve Durbin–Watson (DW) kriterleri dikkate alınarak yapılmıştır. WD modeli veriye yüksek düzeyde uyum göstermiş (MSPE=0.00041, R^2=0.9899) ve en düşük hata değerlerinden birini üretmiştir. MG modeli benzer biçimde güçlü bir performans sergilemiş (MSPE=0.00046, R^2=0.9886) ve gözlenen değerlere yakın tahminler yapmıştır. CD modeli diğer modellere kıyasla düşük açıklama gücüyle (MSPE=0.1063, R^2=0.703) en zayıf uyumu göstermiştir. Altı parametreli GG modeli istatistiksel olarak yüksek uyum sağlamakla birlikte, parametre karmaşıklığı nedeniyle uygulanabilirliği ve stabilitesi diğer modellere göre daha sınırlı bulunmuştur. Dört model birlikte değerlendirildiğinde WD ve MG modellerinin Tuj koyunlarının laktasyon eğrisini temsil etmede en yüksek doğruluk ve istikrarı sunduğu belirlenmiştir. CD modeli düşük performans sergilediğinden uygun görülmemiştir. GR modeli istatistiksel olarak başarılı olmasına rağmen, çok parametreli yapısı ve hesaplama zorlukları sebebiyle pratik uygulamalarda kullanımının sınırlı olabileceği tespit edilmiştir. Sonuç olarak, Tuj koyunlarının laktasyon eğrisinin güvenilir şekilde modellenebilmesi için WD modelinin birincil, MG modelinin ise güçlü bir alternatif olarak kullanılabileceği sonucuna varılmıştır

Anahtar kelimeler: Tuj koyunu; Laktasyon eğrisi; Matematiksel modelleme

ABSTRACT

Accurate modeling of lactation curves is crucial for sheep milk yield management, breeding planning, and reliable yield prediction. This study aimed to apply four different mathematical models to milk yields measured between weeks 3 and 27 in Tuj sheep, compare their predictive performance, and determine the model that best represents the lactation curve of Tuj sheep. The

animal material for the study consisted of 31 Tuj sheep. Lactation curves of Tuj sheep were evaluated using the Wood (WD), Cobby and Le Du (CD), Morant and Gnanasakthy (MG), and Gipson and Grossman (GG) models. Comparisons were made using the MSPE, R^2, and Durbin–Watson (DW) criteria. The WD model showed a high fit to the data (MSPE=0.00041, R^2=0.9899) and produced one of the lowest error values. The MG model performed similarly strongly (MSPE=0.00046, R^2=0.9886) and produced predictions close to the observed values. The CD model showed the poorest fit, with low explanatory power compared to the other models (MSPE=0.1063, R^2=0.703). While the six-parameter GG model provided a statistically high fit, its applicability and stability were found to be more limited than the other models due to parameter complexity. When the four models were evaluated together, it was determined that the WD and MG models offered the highest accuracy and stability in representing the lactation curve of Tuj sheep. The CD model was deemed unsuitable due to its poor performance. Although the GR model was statistically successful, its multi-parameter structure and computational challenges limited its use in practical applications. Consequently, it was concluded that the WD model could be used as the primary model for reliable modeling of the lactation curve of Tuj sheep, while the MG model could be used as a strong alternative.

Keywords: Artificial Intelligence, Autonomous Systems, Ethics, Reliability, Openness.

GİRİŞ

Laktasyon eğrilerinin modellenmesi, koyunlarda süt veriminin biyolojik yapısını açıklamak, verimliliği karşılaştırmak, yönetim ve seleksiyon kararlarını yönlendirmek açısından modern hayvancılık araştırmalarında önemli bir yer tutmaktadır. Laktasyon eğrisi; yükseliş, pik ve düşüş olmak üzere üç temel fazdan oluşmaktadır ve bu fazların şekli ırk, besleme düzeyi, sağım yönetimi, iklim ve genetik yapı gibi faktörlerden güçlü biçimde etkilenmektedir (Guevara et al., 2023a; Guevara et al., 2023b; Barani et al., 2025).

Sığır ve koyunlarda laktasyon eğrilerinin modellenmesinde en yaygın kullanılan yöntemlerden biri Wood (1967) tarafından geliştirilen eksik gamma fonksiyonudur. Wood modeli (WD), basit yapısı ve biyolojik olarak yorumlanabilir parametreleri nedeniyle bireysel olarak ve sürü düzeyinde güvenilir tahminler sağlayabilmektedir. Nitekim Pérez-Segura et al. (2025), Rambouillet koyunlarında yaptıkları çalışmada WD modelinin laktasyon performansındaki değişimleri başarılı biçimde temsil ettiğini ve pik zamanı ile laktasyon persistensisini yüksek doğrulukla tahmin edebildiğini bildirmişlerdir. Bununla birlikte son yıllarda, özellikle Latin Amerika'daki sürülerden elde edilen verilerin heterojen yapıları nedeniyle nonlineer karışık modellerin (NLME) kullanımlarıda yaygınlık kazanmıştır. Guevara et al. (2023a), 42 farklı laktasyon modelini test ettikleri kapsamlı çalışmalarında, Morant & Gnanasakthy (MG), Wood (WD), Papajcsik–Bodero ve Sikka modellerinin öne çıktığını, ancak model uygunluğunun verinin tamlığı, birey sayısı, sağım başlangıç zamanı ve sürü yönetimi koşullarına göre değişebildiğini göstermişlerdir. Özellikle MG ve Sikka modellerinin yüksek uyum sağladığı, ancak bazı bireylerde yakınsama problemleri oluşturduğu da vurgulanmıştır (Guevara et al., 2023a). Benzer şekilde son dönemlerde yapılan çalışmalar, koyun laktasyon eğrilerinin klasik modellerle her zaman tam olarak açıklanamayabileceğini göstermektedir (Castillo-Hernández et al., 2025). Tekel et al. (2019), Awassi koyunlarında klasik modellerden hiçbirinin R^2 değerinin 0.85'i aşamadığını, en iyi uyumun yüksek dereceli polinom modellerle sağlandığını bildirmişlerdir. Ayrıca metabolomik düzeyde yürütülen yeni araştırmalar, enerji dengesi ve glukoneogenez gibi metabolik süreçlerin laktasyon eğrilerinin şeklini doğrudan etkilediğini göstermektedir. Pérez-Segura et al. (2025), calcium propionate takviyesinin hem laktasyon eğrisini hem de metabolik yolakları değiştirdiğini, süt üretiminde belirgin artışa neden olduğunu ortaya koymuştur. İncelediğimiz çalışmalar, laktasyon eğrisinin yalnızca

matematiksel bir ilişki olmadığını; aynı zamanda hayvanın metabolik, genetik ve çevresel koşullarını yansıtan biyolojik bir süreç olduğunu göstermektedir. Bu nedenle, belirli bir koyun genotipi için en uygun eğriyi seçmek bilimsel açıdan ve yetiştiricilik uygulamaları açısından kritik öneme sahiptir (Angele-Hernandez et al., 2013; Barani et al., 2025; Castillo-Hernández et al., 2025).

Bu çalışmanın amacı, Tuj koyunlarının laktasyon eğrilerini modellemek amacıyla dört farklı modelin (Wood modeli, Cobby–Le Du modeli, Morant–Gnanasakthy modeli ve Gipson–Grossman) karşılaştırılarak, bu ırka özgü en uygun model yapısının belirlenmesidir.

MATERYAL ve METOT

Hayvan Materyali

Araştırmada, Tuj koyunlarına ait tamamlanmış laktasyon kayıtları kullanılmıştır. Örneklem büyüklüğü olarak 31 baş Tuj koyununun laktasyon verileri değerlendirmeye alınmıştır. Tüm koyunlar benzer yönetim ve besleme koşulları altında tutulmuş; kuzular doğumu takiben yaklaşık 2.5 aylık olana dek annelerini emmiş ve bu sürenin sonunda sütten kesim yapılmıştır. Sağım verileri laktasyon boyunca düzenli aralıklarla (haftalık ortalamalar şeklinde) kaydedilmiştir.

Matematiksel Modeller

Laktasyon eğrisini tanımlamak için literatürde yaygın olarak kullanılan dört farklı model seçilmiş ve kullanılan modeller Tablo 1'de sunulmuştur. Her bir model, Tuj koyunlarının bireysel süt verim değerlerine uygulanmıştır. Parametre tahminleri ve standart hataları, SAS yazılımının *NLIN (Nonlinear Regression)* prosedürü kullanılarak Gauss-Newton iterasyon algoritması ile elde edilmişlerdir. Model uyumunun değerlendirilmesinde üç temel performans kriteri kullanılmıştır: (1) Ortalama kareler hatası (MSPE), (2) Düzeltilmiş Belirleme Katsayısı (R^2) ve (3) Durbin–Watson istatistiği (DW). MSPE, modelin tahmin ettiği değerlerin gözlemlerden sapmalarının kareler ortalamasını ifade eder ve daha düşük MSPE değeri daha iyi uyumu göstermektedir. R^2 değerleri, modelin verideki toplam varyasyonu açıklama oranını belirtir. DW istatistiği ise model artıklarında (hatalarında) otokorelasyon olup olmadığını test etmek için kullanılmıştır. DW değerinin 2'ye yakın olması artığın rastgele dağılım gösterdiğine (otokorelasyon olmadığına) işaret eder. 2'den düşük değerler pozitif otokorelasyona, 2'den yüksek değerler ise negatif otokorelasyona işaret etmektedir

Table 1. The models for describing lactation curves.

Name	Source	Function of t	Number of parameters
WD	Wood (1967)	$Y_{(t)}=at^{b}e^{-ct}$	3
CD	Cobby and Le Du (1978)	$Y_{(t)}=a - bt - a\ e^{-ct}$	3
MG	Morant and Gnanasakthy (1989)	$Y_{(t)}=e^{(a + bt + ct2 + d/t)}$	4
GG	Gipson and Grossman (1989)	$Y_{(t)}= a_1b_1\,(1\text{-}\tanh^2(b_1(t\text{-}c_1))) + a_2b_2\,(1\text{-}\tanh^2(b_2(t\text{-}c_2)))$	6

BULGULAR

Tuj koyunlarına ait süt verimlerine yukarıda tanımlanan dört model (Wood, Morant–Gnanasakthy (MG), Gipson–Grossman (GG) ve Cobby–Le Du (CD)) ayrı ayrı uygulanmış ve her model için MSPE, R^2 ve DW değerleri hesaplanarak Tablo 2'de sunulmuştur.

Table 2 Tuj koyunlarının laktasyon eğrilerini tanımlamak için modellerin uyum iyiliği istatistiklerinin karşılaştırılması

Models	N	MSPE	R^2	DW
		**	**	N.S.
WD	31	0.0004 ± 0.007^{c}	0.99 ± 0.0004^{a}	3.39±0.22
CD	17	0.106 ± 0.010^{a}	0.70 ± 0.094^{c}	3.63±0.25
MG	9	0.00046 ± 0.008^{c}	0.98 ± 0.056^{a}	3.37±0.28
GG	24	0.013 ± 0.005^{b}	0.94 ± 0.0012^{b}	3.56±0.23

Modellerin performansı, tahmin edilen değerlerin gözlenen süt verimleriyle uyumu üzerinden MSPE ve R^2 ölçütleriyle karşılaştırılmış, ayrıca modellerin yakınsama başarısı ve uygulama kolaylığı da dikkate alınmıştır. WD modeli, tüm bireylerde başarılı bir şekilde çözümleme sağlamış ve genel olarak dengeli bir performans sergilemiştir. Modelin hata değeri (MSPE = 0.0004) oldukça düşük çıkmış, belirleme katsayısı (R^2) 0.99 olarak belirlenmiştir. Tuj koyunlarının haftalık süt verimleri, WD modeline göre istikrarlı şekilde tahmin edilmiş ve model, eğrinin başlangıcından sonuna kadar biyolojik açıdan tutarlı tahminler vermiştir. Parametre tahminleri de istikrarlı bulunmuş; model hiçbir laktasyonda yakınsama sorunu yaşamamıştır.

Morant–Gnanasakthy (MG) modeli, teorik olarak daha esnek bir yapıya sahip olmasına rağmen, veri setinde sınırlı sayıda laktasyonda yakınsama sağlamıştır. Yakınsama sağlanan bireylerde MG modeli WD modelinden sonra en iyi uyumu gösteren model olmuş ve MSPE değeri 0.00046, R^2 değeri ise 0.98 olarak hesaplanmıştır. Bununla birlikte modelin bireylerin önemli bölümünde başarısız olması, tüm sürü bazında kullanılabilirliğini sınırlandırmaktadır.

Table 3. Dört farklı modele ait laktasyon eğrisi parametreleri, pik verim ve pik zamanı için en küçük kare ortalamaları ve standart hatalar

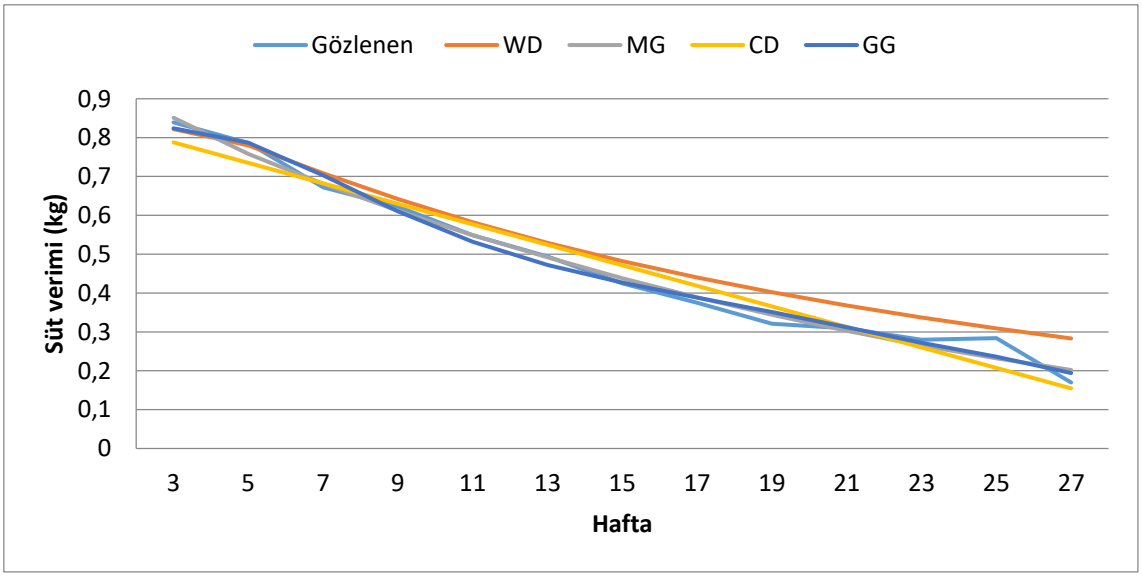
	N	a Mean±S.E.	b Mean±S.E.	c Mean±S.E.	Pik verimi (kg)	Pik zamanı (week)
		**	**	**	**	*
WD	31	0.82 ± 0.13^{ab}	1.30 ± 0.10^{a}	0.28 ± 0.11^{c}	0.902 ± 0.08^{b}	0.90 ± 0.09^{a}
CD	17	0.87 ± 0.28^{ab}	0.026 ± 0.07^{c}	7.33 ± 0.98^{a}	0.845 ± 0.081^{b}	0.68 ± 0.08^{b}
MG	9	-0.095 ± 0.007^{c}	-0.041 ± 0.005^{d}	-0.0006 ± 0.00001^{d}	3.0 ± 0.65^{a}	0.85 ± 0.025^{ab}
GG	24	5.00 ± 0.57^{a}	0.13 ± 0.01^{b}	2.21 ± 0.82^{b}	0.704 ± 0.10^{b}	0.10 ± 0.01^{c}

Gipson–Grossman (GG) modeli iki fazlı yapısıyla laktasyon eğrisinin kompleks dinamiklerini yakalamada istatistiksel olarak güçlü bir uyum göstermiştir. MSPE değeri 0.013 ve R^2 değeri 0.94 ile WD ve MG modellerinden sonra oldukça yüksek bir açıklama gücüne ulaşmıştır. Ancak parametre sayısının fazlalığı nedeniyle model ancak 24 bireyde yakınsama sağlayabilmiştir. Bu durum GG modelinin pratikte sınırlı kullanımına işaret etmiştir. Yakınsama sağlanan bireylerde elde edilen eğriler son derece hassas olsa da modelin aşırı uyum (overfitting) eğiliminde olduğu gözlenmiştir (Grafik 1).

Cobby–Le Du (CD) modeli, diğer modellere kıyasla daha kısıtlı bir uyum sergilemiştir. MSPE değeri 0.106, R^2 değeri ise 0.70 olarak belirlenmiştir. Model özellikle laktasyonun düşüş evresini yeterince doğru temsil edememiş ve doğrusal azalış bileşeni nedeniyle eğrinin doğal eğriselliğini yakalamakta zayıf kalmıştır. Bunun sonucu olarak CD modeli, Tuj koyunlarının laktasyon yapısını tanımlamada diğer modellere göre daha düşük bir başarı göstermiştir.

Model artık analizleri, incelenen modeller için ciddi bir otokorelasyon sorunu olmadığını göstermiştir. Dört modelin de ortalama Durbin–Watson istatistikleri 3 civarında bulunmuştur (3.39–3.63 aralığında). DW değerlerinin 2'nin belirgin üzerinde olması, pozitif yönlü otokorelasyonun olmadığını ve hatta hafif negatif korelasyon eğilimi olabileceğini düşündürmektedir. Kısacası, tüm modeller artıklar açısından bağımsızlık varsayımını büyük ölçüde sağlamışlardır; model tahmin hataları arasında anlamlı bir pozitif ilişki saptanmamıştır. Bu bulgu, özellikle GG modeli için beklenen bir sonuçtur; zira GG modeli otokorelasyonu azaltmak amacıyla iki fazlı yapı önermektedir. Ancak WD ve diğer modellerde de veri doğası gereği artık korelasyonunun sorun teşkil etmediği görülmüştür.

Genel olarak dört model karşılaştırıldığında (Tablo1, Tablo 2), MG modeli WD modeline yakın bir şekilde istatistiksel olarak en düşük hatayı üretmesine karşın, sınırlı uygulanabilirliği nedeniyle tüm sürü için ideal bir seçenek olarak değerlendirilememiştir. GG modelinin uyumu yüksek olmasına rağmen benzer şekilde yakınsama sorunları nedeniyle pratikte uygulamada sorunlar çıkarabilmektedir. CD modeli, hem hata değerleri hem açıklama gücü bakımından en zayıf model olmuştur. WD modeli ise hem yüksek uyum, hem istikrarlı parametre tahmini hem de tüm bireylere uygulanabilirlik açısından en dengeli performansı sunmuş ve Tuj koyunları için en uygun model olarak ortaya çıkmıştır (Grafik 1).



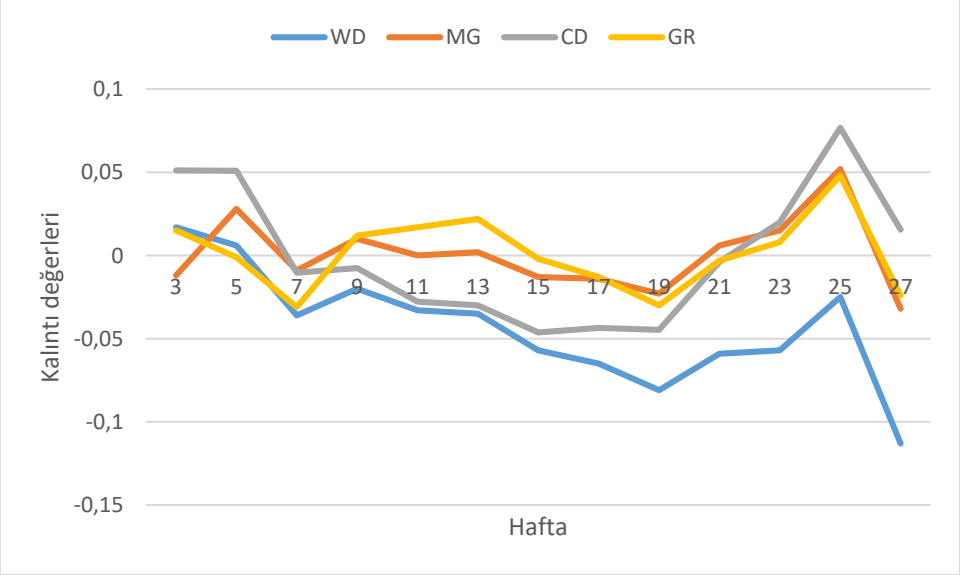
Çizelge 1. Tuj koyunlarında gerçek süt verimleri ve farklı modeller ile tahmin edilen laktasyon eğrileri

TARTIŞMA

Bu çalışmada Tuj koyunlarının laktasyon eğrilerini modellemek amacıyla kullanılan dört farklı eğri fonksiyonunun performansı, model tercihinde hem istatistiksel uyum hem de pratik uygulanabilirlik açısından önemli farklılıklar olduğunu göstermiştir (Grafik 1, 2). Elde edilen sonuçlar, koyunlarda laktasyon eğrisi modellemesine ilişkin son yıllarda yapılan uluslararası çalışmalarla karşılaştırıldığında tutarlı bir bilimsel çerçeve sunmaktadır. WD modeli, bu çalışmada yüksek R^2, ve düşük MSPE değerleri ve tüm bireysel laktasyonlarda sorunsuz

yakınsama sağlamasıyla en dengeli model olarak öne çıkmaktadır. Bu sonuç, Guevara et al. (2023a) tarafından bildirilen bulgularla örtüşmektedir. Söz konusu çalışmada 42 farklı model test edilmiş ve WD modeli, özellikle rastgele etkiler eklenerek yeniden değerlendirildiğinde, biyolojik yorumlanabilirlik ve kararlılık açısından en tutarlı sonuçları vermiştir. Ayrıca Pérez Segura et al. (2025) tarafından Rambouillet koyunlarında yürütülen çalışmada laktasyon eğrisi WD modeli ile başarıyla temsil edilmiş; araştırmacılar model parametrelerinin laktasyon biyolojisi ile doğrudan ilişkili olduğunu, bu nedenle saha koşullarında modelin güvenilir bir araç olarak kullanılabileceğini vurgulamışlardır. WD modelinin bu tür popülasyonlarda üstünlük göstermesinin temel nedenlerinden biri, eğrinin pik sonrası süt verimindeki nonlineer azalışı başarılı şekilde temsil etmesidir. Nitekim Tekel et al., (2019) Awassi koyunlarında WD modelinin klasik eğriler içinde en stabil performansı sergilediğini, ancak daha yüksek uyum isteyen durumlarda polinom temelli esnek modellerin öne çıkabileceğini bildirmişlerdir. Bununla birlikte, bu tür esnek modellerin biyolojik anlamlandırılmasının güç olduğu, bu nedenle özellikle seleksiyon ve yönetim kararlarında WD eğrisinin hala en rasyonel seçenek olduğu belirtilmektedir.

MG modeli, teorik olarak eğrinin hem yükseliş hem düşüş fazını daha ayrıntılı temsil eden esnek yapısıyla dikkat çekmektedir. Bizim çalışmamızda da MG modeli, konverjans sağlanan bireylerde WD modelinden sonra en düşük hatayı ve en yüksek R^2'ye sahip model olmuştur. Bu bulgu, Pollott & Gootwine (2000) tarafından koyunlarda yapılan çalışma ile paralellik göstermektedir. Araştırmacılar MG eğrisinin özellikle süt verimi daha düzenli olan populasyonlarda yüksek doğruluk sunduğunu bildirmişlerdir. Ancak hem bizim çalışmamızda hem de literatürde (Bilgin et al., 2010; Guevara et al., 2023a) belirtildiği gibi MG modelinin en büyük sınırlılığı, yakınsama sorunları ve parametre kararsızlığıdır. Guevara et al., (2023a), MG modelinin özellikle laktasyonun başlangıç döneminin eksik olduğu veya düzensiz sağım verisine sahip koyun popülasyonların da güvenilirliğini kaybettiğini, bazı bireylerde biyolojik açıdan gerçekçi olmayan eğriler oluşturduğunu göstermiştir. Bu nedenle MG modeli yüksek istatistiksel uyum sağlasa bile, sürü genelinde pratik kullanılabilirliği WD modelinin gerisinde kalmaktadır (Grafik 2).



Çizelge 2. Farklı modeller için elde edilen kalıntı değerleri

GG modeli, iki fazlı yapısıyla teoride daha detaylı bir laktasyon dinamiği sunabilmektedir. Bu çalışma, GG modelinin MSPE açısından oldukça güçlü olduğunu ortaya koysa da modelin yüksek parametre sayısı ve bazı bireylerde yakınsama sağlayamaması, literatürle uyumlu şekilde pratik sınırlamayı göstermektedir. Nitekim Grossman & Koops (1988) ile Bilgin et al.

(2010) GG modelinin bireysel hayvan düzeyinde sıkça overfitting yarattığını, özellikle düşük verimli ırklarda modelin ikinci fazı gereksiz şekilde zorlayarak anlamsız eğriler ortaya koyduğunu belirtmişlerdir. Bu durum, Tuj gibi toplam laktasyon verimi düşük olan ırklarda modelin biyolojik gerçekliğini yakalamakta zorlanmasına yol açabilmektedir. GG modeli yüksek doğruluk potansiyeline karşın, pratikte en düşük güvenilirliğe sahip modellerden biri olarak değerlendirilebilir.

CD modeli, pik sonrası dönemi doğrusal varsayması nedeniyle Tuj koyunlarının eğrisel azalış paterniyle uyum sağlayamamıştır. Bu durum literatürde de sıkça rapor edilmektedir. Rambouillet koyunları üzerinde yapılan bir çalışmada (Pérez Segura et al., 2025), laktasyonun pik sonrası fazının doğrusal olmadığını, çevresel ve fizyolojik faktörlerin etkisiyle non-lineer bir düşüş sergilediği gösterilmiştir. Benzer şekilde, Guevara et al. (2023a) CD'nin özellikle kısa laktasyonlu sürülerde yetersiz uyum sergilediğini, WD modelinin ise çok daha tutarlı sonuç verdiğini belirtmişlerdir.

Bu literatür bulguları ışığında, Tuj koyunlarında laktasyon eğrisini temsil etmek için WD modelinin hem teorik hem pratik açıdan en uygun model olduğu söylenebilir. WD modeli en düşük hata ve en yüksek R^2 değerlerine sahip olmasının yanında, tüm bireylerde güvenilir yakınsama sağlayarak sürü düzeyinde en güvenilir tahminleyici olarak öne çıkmaktadır. Güncel çalışmalar (Guevara et al., 2023a; Pérez Segura et al., 2025) koyun popülasyonlarında WD eğrisinin önemini koruduğunu göstermektedir. Öte yandan model seçimi çalışmanın amacına bağlıdır. Tahmin doğruluğunun kritik olduğu durumlarda spline tabanlı eğriler veya yüksek dereceli polinomlar tercih edilebilirken, biyolojik yorumlanabilirlik, seleksiyon uygulamaları ve saha yönetimi söz konusu olduğunda WD modeli en rasyonel ve güvenilir seçenek olmayı sürdürmektedir.

SONUÇ

Bu çalışmada Tuj koyunlarının laktasyon eğrilerini modellemek amacıyla dört farklı fonksiyon (Wood, Morant–Gnanasakthy, Gipson–Grossman ve Cobby–Le Du) karşılaştırılmış ve modellerin istatistiksel uyum ölçütleri ve pratik uygulanabilirlikleri birlikte değerlendirilmiştir. Elde edilen bulgular, her modelin farklı güçlü yönleri olsa da Tuj koyunlarının laktasyon yapısı göz önüne alındığında en dengeli ve güvenilir performansın WD modeli tarafından sağlandığını göstermiştir. Genel olarak değerlendirildiğinde, WD modelinin tüm bireylere sorunsuz uygulanabilmesi, istikrarlı parametre kestirimleri üretmesi ve hata ölçütleri açısından diğer modellerden daha iyi değerlere sahip olması nedeniyle pratik kullanım açısından öne çıktığı tespit edilmiştir.

KAYNAKLAR

Angeles-Hernandez, J.C., Albarrán-Portillo, B., Gomez Gonzalez, A.V., Pescador Salas, N. & Gonzalez-Ronquillo, M. (2013). Comparison of mathematical models applied to F1 dairy sheep lactations in organic farm and environmental factors affecting lactation curve parameter. *Asian-Australasian Journal of Animal Sciences*, 26(8), 1119-1126.

Barani, S., Pahlavan, R., Nazari, B.M., Yeganeh, A.T., Sharif, A.A. & Farhangfar, S.H. (2025). Determining the best predictive function to mathematically describe the lactation curve of primiparous Murcia does in Iran. *Tropical Anim. Health. Prod.* 57, 348.

Bilgin O.C., Esenbuga N. & Davis M. (2010). Comparison of models for describing the lactation curve of Awassi, Morkaraman and Tushin sheep. *Arch. Tierzucht.* 53, 447-456.

Castillo-Hernández, G., Hernández-Mendo, O., Suárez-Espinosa, J., Alcántara-Carbajal, J. L., Mendoza-Pedroza, S. I., &Torres-Hernández, G. (2025). Estimation of lactation persistency in a population of Rambouillet ewes utilizing five mathematical methods. *Agro Productividad*.

Grossman, M. & Koops, W.J. (1988) Multiphasic analysis of lactation curves in dairy cattle. *J Dairy Sci.* 71, 1598-608.

Guevara, L.P.G., Gloria, L.S., Benaouda, M., Teuntle-Lopez, I., Valdes-Cordoba, X.S., Angeles-Hernandez, J.C., Aniceto, E.S. & Acero, A.P. (2023a). The shape of curve lactation of crossbred dairy sheep affects the fitting of empirical and mechanistic models. *Palacio de Convenciones. Zacatecas, Zac*., México. Abril 26-28.

Guevara, L., Castro-Espinoza, F., Fernandes, A.M., Benaouda, M., Muñoz-Benítez, A.L., del Razo-Rodríguez, O.E., Peláez-Acero, A. & Angeles-Hernandez, J.C. (2023b). Application of machine learning algorithms to describe the characteristics of dairy sheep lactation curves. *Animals*, 13, 2772.

Perez Segura, L.F., Lee-Rangel, H.A., Flores Ramirez, R., Garcia-Lopez, J.C., Alvarez-Fuentes, G., Vazquez Valladolid, A., Hernandez-Garcia, P.A., Negrete Sanchez, O. & Rendon Huerta, J.A. (2025). Impact of Calcium Propionate Supplementation on the Lactation Curve and Milk Metabolomic Analysis on Rambouillet Ewes. *Vet. Sci*. 12, 79.

Pollott, G.E. & Gootwine, E. (2000) Appropriate mathematical models for describing the complete lactation of dairy sheep. *Animal Sci*, 71, 197-207.

Tekel, N., Şireli, H.D., Karataş, A., Vural, M.E., Koncagül, S. & Tutkun, M. (2019). Comparison of different lactation curve models to describe lactation curve in Awassi sheep raised in Turkey. *Applied Ecology and Environmental Research*, 17(6), 15507-15517.

Wood, P.D.P. (1967). Algebraic model of the lactation curve in White I. M.S., Thompson R. and Brotherstone S. (1999). Genetic cattle. *Nature*. **216,** 164-165.

EFFECTS OF FUNGICIDES ON NON-TARGET FUNGAL COMMUNITIES IN THE PLANT PHYLLOSPHERE

FUNGİSİTLERİN BİTKİ FİLLOSFERİNDEKİ HEDEF DIŞI FUNGUS TOPLULUKLARI ÜZERİNE ETKİLERİ

Araş. Gör. Ömer Ümit OKÇU

Tekirdağ Namık Kemal University, Faculty of Agriculture, Department of Plant Protection, Tekirdağ, Türkiye

ORCID ID: https://orcid.org/0000-0002-4809-4398

Prof. Dr. Nuray ÖZER

Tekirdağ Namık Kemal University, Faculty of Agriculture, Department of Plant Protection, Tekirdağ, Türkiye

ORCID ID: https://orcid.org/0000-0001-6876-7580

ABSTRACT

The plant phyllosphere has a complex microbial community that includes epiphytic and endophytic fungi. Beneficial fungi within this community play important roles in various ecological processes such as surface competition, biofilm formation, support of the nutrient cycle and limitation of pathogen colonization. However, the fungicides commonly applied in agricultural production have the potential to affect not only target fungal pathogens but also the beneficial fungal populations that are naturally present in the phyllosphere. Fungicide applications may selectively alter fungal diversity and community composition on the phyllosphere, leading to reductions in certain epiphytic or endophytic fungi. Conversely, competitive epiphytic groups that exhibit resistance or tolerance to fungicide treatments may remain unaffected by some active ingredients and thus gain importance as potential biological control agents. Consequently, in fungicide use strategies, non-target effects need to be taken into consideration, chemical applications need to be optimized in terms of dose, timing, and selectivity, and integrated approaches compatible with biological control need to be developed. This review article presents the ecological roles of epiphytic and endophytic fungal communities in the plant phyllosphere and the effects of fungicide applications on non-target groups in light of current studies.

Key Words: Phyllosphere, Fungal Community, Beneficial Fungi, Fungicide Impact, Non-Target Effects

ÖZET

Bitki filosferi, epifitik ve endofitik fungusları içeren karmaşık bir mikrobiyal topluluğa sahiptir. Bu topluluk içinde yer alan yararlı funguslar; yüzey rekabeti, biyofilm oluşumu, besin döngüsünün desteklenmesi ve patojen kolonizasyonunun sınırlandırılması gibi çeşitli ekolojik

süreçlerde önemli roller üstlenmektedir. Ancak tarımsal üretimde yaygın olarak kullanılan fungisitler, yalnızca hedef fungal patojenleri değil, aynı zamanda fillosferde doğal olarak bulunan yararlı fungal popülasyonları da etkileyebilmektedir. Fungisit uygulamaları, fillosferdeki fungal çeşitliliği ve topluluk kompozisyonunu seçici biçimde değiştirebilmekte; bazı epifitik ya da endofitik yaşayan fungusların azalmasına yol açabilmektedir. Buna karşılık, fungisit uygulamalarına karşı direnç veya tolerans gösteren rekabetçi epifitik gruplar, bazı etkili maddeli fungisitlerden etkilenmemeleri nedeniyle potansiyel biyolojik mücadele ajanları olarak önem kazanmaktadır. Bu nedenle fungisit kullanım stratejilerinde hedef dışı etkilerin dikkate alınması, kimyasal uygulamaların doz, zamanlama ve seçicilik açısından optimize edilmesi ve biyolojik mücadele ile uyumlu entegre yaklaşımların geliştirilmesi gerekmektedir. Bu derleme makalesi, bitki fillosferindeki epifitik ve endofitik fungus topluluklarının ekolojik rollerini ve fungisit uygulamalarının hedef dışı gruplar üzerindeki etkilerini mevcut çalışmalar ışığında sunmaktadır.

Anahtar Kelimeler: Fillosfer, Fungal Topluluk, Yararlı Funguslar, Fungisit Etkisi, Hedef Dışı Etkiler

GİRİŞ

Bitki fillosferi, bitkinin toprak üstü organlarını kaplayan ve hem yüzeyde hem de iç dokularında çok çeşitli mikroorganizmaların yaşadığı karmaşık bir ekosistemdir. Yaprak yüzeyini ve iç dokularını kapsayan bu bölge, besin açısından sınırlı fakat mikrohabitat çeşitliliği bakımından oldukça zengin, dinamik bir mikrobiyal yaşam alanı olarak tanımlanmaktadır (Osono, 2006). Kütikula, epidermis, stomalar ve farklı tipte tüylerden oluşan yaprak yüzeyi, mikroorganizma kolonizasyonunun gerçekleştiği heterojen bir ortam sağlamaktadır (Sivakumar et al., 2020). Bunlar arasında salgı üreten tüyler; polisakkarit tuzları, lipitler, uçucu bileşikler ve proteinler gibi bileşikleri salgılayarak mikroorganizma kolonizasyonuna doğrudan katkıda bulunurken, salgı üretmeyen tüyler ışık emilimi, su geriliminin düzenlenmesi ve kuraklığa dayanıklılık gibi fiziksel özellikleriyle dolaylı bir etki oluşturmaktadır (Hirano & Upper, 1983). Benzer şekilde, kütikula yüzeyinin kimyasal bileşimi ve stomaların morfolojik özellikleri, fillosferde kolonize olabilen mikroorganizma topluluklarının bileşimini şekillendirmektedir. Bu topluluklar arasında, özellikle biyotik ve abiyotik streslere karşı dayanıklılık sağlayan yararlı mikroorganizmaların ekolojik ve işlevsel önemi giderek daha iyi anlaşılmaktadır.

Fillosferde yer alan yararlı funguslar, yaşam biçimlerine göre epifitik ve endofitik olmak üzere iki temel grupta değerlendirilmektedir. Epifitik funguslar bitki dokusuna girmeden yaprak yüzeyinde kolonize olmakta; yüzeyde biriken organik maddeleri, mumsu kütikula bileşenlerini ve bitkiden sızan karbon kaynaklarını kullanarak hem kendi gelişimlerini sürdürmekte hem de besin döngüsüne katkı sağlamaktadır. Endofitik funguslar ise konukçu bitkinin iç dokularına giren, çoğu durumda belirti oluşturmadan gelişebilen ve simbiyotik özellikler gösterebilen organizmalardır (Osono, 2006; Sivakumar et al., 2020). Birçok fillosfer fungus türü ekolojik açıdan esneklik gösterebilmekte; uygun koşullarda epifitik yaşamdan endofitik faza geçiş yapabilmekte veya tersine dönebilmektedir (Kharwar et al., 2010; Porras-Alfaro & Bayman, 2011; Thomas et al., 2024). Ayrıca toprak, bitkinin toprak üstü organlarına taşınarak fillosfere yerleşebilen endofitik funguslar için önemli bir inokulum kaynağı oluşturabilmektedir (Zarraonaindia et al., 2015).

Son yıllarda fillosfer kökenli yararlı mikroorganizmaların sentetik mikrobiyal topluluklar (SynComs) hâlinde yeniden yapılandırılarak bitkilere uygulanması, bitki koruma alanında yeni ve umut vadeden bir yaklaşım olarak öne çıkmaktadır (Sarver et al., 2025). Bu çalışmalar, epifitik ve endofitik yararlı fungusların patojen baskılama, savunma reaksiyonlarının uyarılması ve kolonizasyon direncinin artırılması gibi işlevlerinin, kontrollü mikrobiyal

topluluklar aracılığıyla güçlendirilebileceğini göstermektedir. Bazı yararlı fungus türlerinin fillosfer ortamında kolonize olabilme kapasitesi, SynCom yaklaşımının fungus temelli biyolojik kontrol stratejilerine uyarlanabileceğine işaret etmektedir.

Tarımsal üretimde yaygın olarak kullanılan fungisitler, hedef patojenlerin kontrolünde etkili olmakla birlikte, fillosferde yer alan yararlı epifitik ve endofitik fungus toplulukları üzerinde belirgin hedef dışı etkilere yol açabilmektedir. Fungisit uygulamaları; fungal çeşitlilikte azalma, duyarlı türlerin baskılanması, toleranslı türlerin öne çıkması ve mutualistik ağların zayıflaması gibi sonuçlar doğurabilmektedir (Teixidó et al., 1999; Moulas et al., 2013; Karlsson et al., 2014; Knorr et al., 2019; Noel et al., 2022; Sumbula et al., 2022; Wu et al., 2023). Endofitik fungus topluluklarının sistemik fungisitlerle baskılanması konukçu savunmasının zayıflamasına; epifitik fungus topluluklarının azalması ise yüzey patojenlerinin daha kolay kolonize olmasına zemin hazırlayabilmektedir. Dolayısıyla fungisit uygulamalarının fillosfer mikrobiyotası üzerinde dolaylı fakat önemli etkiler yarattığı açıktır. Fillosferdeki yararlı fungus topluluklarının korunması, sürdürülebilir hastalık yönetimi ve biyolojik kontrol stratejilerinin etkinliği açısından kritik önem taşımaktadır (Karlsson et al., 2014).

Bu derleme, tarımda kullanılan fungisitlerin fillosferde bulunan yararlı epifitik ve endofitik fungus toplulukları üzerindeki etkilerini ekolojik, fonksiyonel ve uygulamaya dönük bir bakış açısıyla değerlendirmeyi amaçlamaktadır. Bu kapsamda, fillosferde yer alan fungusları etkileyen abiyotik ve biyotik faktörler ile farklı bitkilerde hedeflenen ve hedef dışı fungusların fungisitlere verdikleri yanıtlar mevcut literatür ışığında ele alınmıştır.

FİLLOSFERDE BULUNAN FUNGUSLARI ETKİLEYEN FAKTÖRLER

Abiyotik Faktörler

Fillosferdeki epifitik ve endofitik fungus topluluklarının kompozisyonu, doğrudan dış çevreye maruz kalmaları nedeniyle sıcaklık, UV radyasyonu, yağış, nem ve rüzgâr gibi çeşitli iklimsel faktörler tarafından güçlü biçimde etkilenmektedir (Gomes et al., 2018). Mevsimsel değişiklikler özellikle rüzgâr hızı ve ortalama sıcaklık üzerinden belirleyici olurken, güneş ışığının yoğun olduğu yaprak bölgelerinde UV'ye daha dayanıklı koyu renkli fungus türlerinin baskın hâle gelebildiği bildirilmektedir (Gessler et al., 2014; Kembel & Mueller, 2014). Genellikle ilkbaharda epifitik ve endofitik fungus çeşitliliği sonbahara kıyasla daha yüksek olmakta (Collado et al., 1999; Osono, 2008), yağışlı dönemlerde ise yaprak yüzeyinde oluşan su tabakası spor çimlenmesini kolaylaştırırken yoğun yağışların fungusların çoğalma yapılarının yaprak yüzeyinden uzaklaşmasına neden olabildiği belirtilmektedir (Collado et al., 1999; Gomes et al., 2018). Yaprak yüzeyinin heterojen bir yapıya sahip olması fungusların yüzeye tutunma, gelişme ve rekabet etme kapasitesini önemli ölçüde şekillendirmektedir (Beattie, 2011; Vorholt, 2012). Bitkiye özgü yapısal özellikler, özellikle kütikula yapısı, yüzey dokusu, tüy yoğunluğu ve stomaların konumu, epifitik ve endofitik fungusların fillosferdeki yerleşim başarısını doğrudan etkilemektedir. Ayrıca tüylerin kimyasal bileşimi ve salgı üretme özellikleri, belirli bölgelerde fungal birikimi artırarak bazı türlerin kolonizasyon kapasitesini güçlendirebilmektedir (Hirano & Upper, 1983). Bitkinin farklı organları fungus türlerini belirleyen diğer yapısal faktörlerdendir. Yaprak ve sürgün gibi organlarda bulunan epifitik ve endofitik fungus topluluklarının hem tür zenginliği hem de baskın türler açısından belirgin biçimde farklılaştığı ve bu farklılıkların organlara özgü doku yapısı ile kimyasal bileşimden kaynaklandığı bildirilmektedir (Gomes et al., 2018). Güneş alan veya gölge konumlar arasındaki çevresel farklılıklar belirli ölçüde varyasyon yaratsa da fillosfer fungal kompozisyonunu şekillendirmede asıl belirleyici unsurun organ tipi olduğu ve organların kendilerine özgü fungal topluluklara sahip olduğu belirtilmektedir (Laforest-Lapointe et al., 2016). Fenolojik süreçler de fillosferdeki fungus topluluklarının dinamiklerini etkileyen önemli

bir diğer faktördür. Yaprak yaşlanmasıyla birlikte doku bütünlüğünün zayıflaması ve besin içeriğinde meydana gelen değişimler, bazı endofitik fungusların yaprak içi dokularda daha hızlı çoğalmasına olanak tanımaktadır. Birçok fillosfer fungusunda epifitik, endofitik ve saprofitik evreler arasında geçişlerin yaşlanan yapraklarda daha belirgin hâle geldiği belirtilmektedir (Osono, 2006). Yine yaprak dökümü sonrasında endofitik türlerin baskınlığının azalmasıyla bazı epifitik funguslar iç dokuları kolonize edebilmektedir (Cabral, 1985; Stone, 1987).

Biyotik Faktörler

Fillosferde bulunan yararlı epifitik ve endofitik funguslar, patojen funguslarla aynı yaşam alanını paylaşarak bitki sağlığının sürdürülmesinde önemli biyotik düzenleyiciler hâline gelmektedir. Bu hedef dışı funguslar, yaprak yüzeyindeki sınırlı besin kaynaklarına ve yararlı fungal topluluklar tarafından oluşturulan kolonizasyon alanlarına hızla yerleşerek patojenlere karşı belirgin bir besin ve alan rekabeti yaratmakta; özellikle karbon içeren yüzey salgıları ve hücreler arası boşluklardaki besinlere erişimde üstünlük sağlayabilmektedir (Sohrabi et al., 2023). Yararlı epifitik türlerin erken ve yoğun yüzey kolonizasyonu, patojen fungusların tutunma ve çimlenmesini sınırlandırarak güçlü bir kolonizasyon direnci oluşturmaktadır (De Mandal & Jeon, 2023). Endofitik funguslar ise bitki dokuları içinde patojenlerle rekabet ederek ve konukçu savunmasını uyararak dolaylı bir koruma sağlamaktadır (Sivakumar et al., 2020).

FUNGİSİTLERİN FİLLOSFERDE BULUNAN HEDEF DIŞI FUNGUSLARA ETKİSİ

Tarımsal üretimde fungisitlerin temel kullanım amacı, hedef patojenleri baskılayarak hastalık kontrolünü sağlamaktır. Ancak yapılan çalışmalar, fungisit uygulamalarının hedef patojenlere etkili olurken, bitki fillosferinde doğal olarak bulunan epifitik ve endofitik hedef dışı fungus topluluklarını da farklı düzeylerde etkileyebildiğini ortaya koymaktadır. Oysa fillosferde bulunan yararlı funguslar; patojenlerle rekabet, antagonizm, besin döngüsü ve savunma reaksiyonlarının teşviki gibi mekanizmalar yoluyla bitki sağlığının korunmasında kritik bir rol üstlenmektedir. Bu nedenle hedef patojen baskısının sağlandığı sistemlerde, fungisit uygulamalarının bu yararlı mikrobiyal dengeyi ne ölçüde ve hangi yönde değiştirdiğinin ortaya konulması, sürdürülebilir ve çevreyle uyumlu bitki koruma yaklaşımları açısından özel bir önem taşımaktadır. Çeşitli bitki türlerinde hedef patojene karşı kullanılan fungisitlerin fillosferde bulunan hedef dışı fungus türleri üzerindeki etkilerini birlikte değerlendiren başlıca çalışmalar ve elde edilen bulgular Tablo 1'de sunulmuştur.

Tablo 1. Fungisitlerin hedef fungal patojen ve fillosferdeki hedef dışı fungal topluluklar üzerine etkileri

Bitki	**Fungisitler**	**Hedef fungal patojenler / baskılanma durumu**	**Hedef dışı funguslar /baskılanma durumu**	**Kaynak**
Elma	Kükürt + captan; boraks + kükürt; flusilazol	Depo çürüklük etmenleri *Penicillium expansum* ve *Botrytis cinerea* / sezon boyunca çok düşük yoğunlukta izole edilmiştir	**Baskılanan:** *Cladosporium* spp.; **Geçici olarak baskılanan,** çekirdek çürüklüğü ile ilişkili latent patojen *Alternaria* spp.. **Daha az etkilenen mayalar**: *Candida* spp., *Cryptococcu*s spp. *Debaryomyces* spp., *Hansenula* spp., *Pichia* spp. (beyaz), *Rhodotorula* spp., *Sporobolomyces* spp.(pembe)	Teixidó et al., 1999

Tablo 1. (Devamı)

Bitki	**Fungisitler**	**Hedef fungal patojenler / baskılanma durumu**	**Hedef dışı funguslar /baskılanma durumu**	**Kaynak**
Buğday	Azoxystrobin, bixafen, cyprodinil, difenoconazole, fenpropimorph, metrafenone, picoxystrobin, prochloraz, propiconazole, prothioconazole, pyraclostrobin	*Zymoseptoria tritici* (Septoria yaprak lekesi), *Blumeria graminis* (külleme) / tutarlı bir azalma görülmemiş; *Puccinia striiformis* (sarı pas). / belirgin biçimde baskılanmıştır.	**Baskılanan:** *Aureobasidium pullulans*, *Dioszegia* sp., *Leucosporidium golubevii*. **Göreceli bolluğu artan tür:**: *Phaeosphaeria juncophila*	Karlsson et al., 2014
	1.Epoxiconazole + pyraclostrobin + boscalid, 2.Epoxiconazole + fluxapyroxad, 3.Prothioconazole + bixafen	**Baskılanan*:*** *P. striiformis* (3. karışım hariç). *Z. tritici* (1. karışım hariç), *Parastagonospora nodorum* (yaprak ve başak yanıklığı), *Didymella exitialis* (yaprak lekesi), *B. graminis.* **Artan:** *Pyrenophora tritici-repentis* (sarı yaprak lekesi); *Microdochium nivale* (kar küfü)	**Baskılanan*:*** *Lewia infectoria* (patojen olmayan), *Dioszegia hungarica* (1. karışım hariç) **Artan**: *Cladosporium* spp., *Sporobolomyces* sp., *C. victoriae* (1. karışım hariç), *C. tephrensis, C. stepposus* (3. karışım hariç), *Udeniomyces pannonicus*	Knorr et al., 2019
Biber	Metalaxyl (fungisit, toprak ve yapraktan);	**Etkilenmeyen:** *Erysiphe sp.* (külleme etmeni) ve *Cladosporium sp.* (yaprak patojeni)	Saccharomycetes sımıfı ile ilişkili bir moleküler birim ve endofitik fungus *Periconia macrospinosa* uyarılmıştır	Moulas et al., 2013
Domates	Propineb, iprodione + carbendazim	**Azalma:** *Alternaria alternata* (erken yaprak yanıklığı etmeni); Ayrıca yaprak hastalıklarıyla ilişkili patojenik cinsler olarak bildirilen *Cladosporium*, *Corynespora* ve *Pseudocercospora* da tespit edilmiştir	**Azalma:** *Acremonium* ve *Malassezia* (iprodione + carbendazim uygulamasında); *Coprinopsis* (propineb uygulamasında)	Sumbula et al., 2022
Hıyar	Tebuconazole (sentetik triazol); kükürt (inorganik fungisit)	**Azalma:** Külleme etmeni *Podosphaera xanthii* her iki fungisit tarafından da baskılanmıştır. Bu azalma kükürt uygulamasında daha belirgin olmuştur. Ancak *Podosphaera* ile birlikte hıyarda yaprak hastalıklarıyla ilişkili patojenik cinsler *Alternaria*, *Curvularia* ve *Cladosporium* da tespit edilmiştir.	**Tebuconazole:** Hedef dışı etki daha belirgin olup *Fereydounia*, *Moesziomyces* ve *Phaeosphaeria*'nın topluluktaki oranı azalmış, fırsatçı/patojenik potansiyeli bulunan *Nigrospora*'nın topluluktaki oranı artmıştır; *Sympodiomycopsis* cinsi ise tebuconazole uygulamasında toplulukta oran artışı göstermiştir. **Kükürt:** Hedef dışı fungal topluluk üzerinde daha sınırlı etki gözlenmiş, *Iodophanus* başta olmak üzere çoğu cinsin topluluktaki oranı büyük ölçüde korunmuştur.	Wu et al., 2023

Fungisit uygulamalarıyla baskılanan bazı hedef dışı epifitik ve endofitik fungusların, patojenlere karşı biyokontrol potansiyeline sahip olduğu bilinmektedir. Bu türlerden yüksek düzeyde etki gösterenlerden bazıları (≥%70) Tablo 2'de verilmiştir. Söz konusu yararlı funguslar; besin ve yer için rekabet, biofilm oluşumu, uçucu bileşik, toksin ve litik enzim üretimi ile mikoparazitizm gibi çeşitli etki mekanizmalarının büyük bir kısmına sahiptirler (Avis et al., 2001; Castoria et al., 2001; Buxdorf et al., 2013; Öztekin et al., 2023).

Tablo 2. Bazı fillosfer kökenli fungusların farklı patojen funguslara karşı antagonistik etkileri

Fillosfer fungusu	**Etkili olduğu patojen fungus**	***In vitro***	***In vivo***	**Kaynak**
Aureobasidium pullulans	*Botrytis cinerea*	+	+	Lima et al., 1997
	Blumeria graminis f. sp. *tritici*	–	+	De Curtis et al., 2012
	Aspergillus tubingensis	+	+	Pantelides et al., 2015
Candida spp.	*Penicillium* spp.	+	–	da Cunha et al., 2018
Debaryomyces spp.	*Mucor circinelloides*	+	–	Medina-Córdova et al., 2018
	Aspergillus sp.	+	–	
	Fusarium proliferatum	+	–	
	Fusarium subglutinans	+	–	
	Monilinia fructicola	+	+	Czarnecka et al., 2019
Moesziomyces spp. (syn. *Pseudozyma*)	*Podosphaera fuliginea*	+	–	Avis et al., 2001
	Botrytis cinerea	+	+	Buxdorf et al., 2013
Rhodotorula spp.	*Aspergillus carbonarius*	+	–	Tryfinopoulou et al., 2020
	Moniliophthora roreri	+	–	Estrela Junior et al., 2022

SONUÇ

Bitki fillosferi, epifitik ve endofitik funguslardan oluşan ve bitki sağlığının korunmasında önemli ekolojik işlevler üstlenen dinamik bir mikrobiyal ekosistemdir. Ancak fungisitler, patojenleri baskılamadaki etkinliklerine karşın, çoğu zaman fillosferdeki yararlı fungal toplulukları da olumsuz etkileyerek mikrobiyal çeşitliliğin azalmasına ve topluluk dengesinin bozulmasına yol açabilmektedir. Bu durum, doğal biyolojik kontrol potansiyelinin zayıflamasına ve fırsatçı türlerin baskınlaşmasına neden olabilmektedir. Bu nedenle fungisit kullanımının, yalnızca hedef patojenler değil, hedef dışı yararlı funguslar da dikkate alınarak planlanması gerekmektedir. Daha seçici fungisitlerin tercih edilmesi, uygulama sıklığının ve zamanının optimize edilmesi ve biyolojik kontrol stratejilerinin kimyasal uygulamalarla entegre edilmesi, fillosfer mikrobiyal dengesinin korunması açısından kritik öneme sahiptir. Sürdürülebilir bitki sağlığı yönetimi, patojen kontrolü ile birlikte fillosferdeki yararlı epifitik ve endofitik fungal toplulukların korunmasını da esas alan ekolojik temelli yaklaşımlarla mümkün olacaktır.

KAYNAKLAR

Avis, T. J., Caron, S., Boekhout, T., Hamelin, R. C., & Bélanger, R. R. (2001). Molecular and physiological analysis of the powdery mildew antagonist *Pseudozyma flocculosa* and related fungi. *Phytopathology*,*91*(3), 249-254. https://doi.org/10.1094/PHYTO.2001.91.3.249

Beattie, G. A. (2011) Water relations in the interaction of foliar bacterial pathogens with plants. *Annual Review of Phytopathology*, *49*, 533–555 https://10.1146/annurev-phyto-073009-114436

Buxdorf, K., Rahat, I., Gafni, A., & Levy, M. (2013). The epiphytic fungus *Pseudozyma aphidis* induces jasmonic acid-and salicylic acid/nonexpressor of PR1-independent local and systemic resistance. *Plant physiology*, *161*(4), 2014-2022. https://doi.org/10.1104/pp.112.212969

Cabral, D. (1985). Phyllosphere of *Eucalyptus viminalis*: Dynamics of fungal populations. *Transactions of the British Mycological Society*, *85*, 501–511. https://doi.org/10.1016/S0007-1536(85)80047-4

Castoria, R., De Curtis, F., Lima, G., Caputo, L., Pacifico, S., et al. (2001). *Aureobasidium pullulans* (LS-30), an antagonist of postharvest pathogens of fruits: Study on its modes of action. *Postharvest Biology and Technology, 22*, 7–17. https://doi.org/10.1016/S0925-5214(00)00186-1

Collado, J., Platas, G., González, I., & Peláez, F. (1999). Geographical and seasonal influences on the distribution of fungal endophytes in *Quercus ilex*. *New Phytologist*, *144*, 525–532. https://doi.org/10.1046/j.1469-8137.1999.00533.x

Czarnecka, M., Zarowska, B., Połomska, X., Restuccia, C., & Cirvilleri, G. (2019). Role of biocontrol yeasts *Debaryomyces hansenii* and *Wickerhamomyces anomalus* in plants' defence mechanisms against *Monilinia fructicola* in apple fruits. *Food Microbiology*, *83*, 1–8. https://doi.org/10.1016/j.fm.2019.04.004

da Cunha, T., Ferraz, L. P., Wehr, P. P., & Kupper, K. C. (2018). Antifungal activity and action mechanisms of yeast isolates from citrus against *Penicillium italicum*. *International Journal of Food Microbiology, 276*, 20–27. https://doi.org/10.1016/j.ijfoodmicro.2018.03.019

De Curtis, F., De Cicco, V., & Lima, G. (2012). Efficacy of biocontrol yeasts combined with calcium silicate or sulphur for controlling durum wheat powdery mildew and increasing grain yield components. *Field Crops Research, 134*, 36–46. https://doi.org/10.1016/j.fcr.2012.04.014

De Mandal, S., & Jeon, J. (2023). Phyllosphere microbiome in plant health and disease. *Plants, 12*(19), 3481. https://doi.org/10.3390/plants12193481

Estrela Junior, A. D. S., Solis, K., Pimenta Neto, A. A., Vera, D. I., Garzon, I., Penaherrera, S., Diorato, V. S., Gramacho, K. P., & Laranjeira, D. (2022). Effect of antagonistic yeasts from cacao tissues on controlling growth and sporulation of *Moniliophthora roreri*. *Biological Control, 172*, 104956. https://doi.org/10.1016/j.biocontrol.2022.104956

Gessler, N. N., Egorova, A. S., & Belozerskaya, T. A. (2014). Melanin pigments of fungi under extreme environmental conditions. *Applied Biochemistry and Microbiology*, *50*, 105–113. 10.7868/s0555109914020093

Gomes, T., Pereira, J. A., Benhadi, J., Lino-Neto, T., & Baptista, P. (2018). Endophytic and epiphytic phyllosphere fungal communities are shaped by different environmental factors in a Mediterranean ecosystem. *Microbial Ecology*, *76*(3), 668–679. https://doi.org/10.1007/s00248-018-1161-9

Hirano, S. S., & Upper, C. D. (1983). Ecology and epidemiology of foliar bacterial plant pathogens. *Annual Review of Phytopathology*, *21*, 243–269. https://doi.org/10.1146/annurev.py.21.090183.001331

Karlsson, I., Friberg, H., Steinberg, C., & Persson, P. (2014). Fungicide effects on fungal community composition in the wheat phyllosphere. *PLOS One*, *9*(11), e111786. https://doi.org/10.1371/journal.pone.0111786

Kembel, S. W., & Mueller, R. C. (2014). Plant traits and taxonomy drive host associations in tropical phyllosphere fungal communities. *Botany*, *92*, 303–311. https://doi.org/10.1139/cjb-2013-0194

Kharwar, R. N., Gond, S. K., Kumar, A., & Mishra, A. A. (2010). A comparative study of endophytic and epiphytic fungal association with leaf of *Eucalyptus citriodora* Hook., and their antimicrobial activity. *World Journal of Microbiology and Biotechnology, 26,* 1941–1948. https://doi.org/10.1007/s11274-010-0374-y

Knorr, K., Jørgensen, L. N., & Nicolaisen, M. (2019). Fungicides have complex effects on the wheat phyllosphere mycobiome. *PLOS One, 14*(3), e0213176. https://doi.org/10.1371/journal.pone.0213176

Laforest-Lapointe, I., Messier, C., & Kembel, S. W. (2016). Tree phyllosphere bacterial communities: Exploring the magnitude of intra- and inter-individual variation among host species. *PeerJ Life and Environment, 4,* e2367. https://doi.org/10.7717/peerj.2367

Lima, G., Ippolito, A., Nigro, F., & Salerno, M. (1997). Effectiveness of *Aureobasidium pullulans* and *Candida oleophila* against postharvest strawberry rots. *Postharvest Biology and Technology, 10*(2), 169–178. https://doi.org/10.1016/S0925-5214(96)01302-6

Medina-Córdova, N., Rosales-Mendoza, S., Hernández Montiel, L. G., & Angulo, C. (2018). The potential use of *Debaryomyces hansenii* for the biological control of pathogenic fungi in food. *Biological Control, 121,* 216–222. https://doi.org/10.1016/j.biocontrol.2018.03.002

Moulas, C., Petsoulas, C., Rousidou, K., Perruchon, C., Karas, P., & Karpouzas, D. G. (2013). Effects of systemic pesticides imidacloprid and metalaxyl on the phyllosphere of pepper plants. *BioMed Research International, 2013,* 969750. https://doi.org/10.1155/2013/969750

Osono, T. (2006). Role of phyllosphere fungi of forest trees in the development of decomposer fungal communities and decomposition processes of leaf litter. *Canadian Journal of Microbiology, 52*(8), 701–716. https://doi.org/10.1139/w06-023

Osono, T. (2008). Endophytic and epiphytic phyllosphere fungi of *Camellia japonica*: Seasonal and leaf age-dependent variations. *Mycologia, 100,* 387–391. https://doi.org/10.3852/07-110r1

Öztekin, S., Dikmetas, D. N., Devecioğlu, D., Acar, E. G., & Karbancioglu-Guler, F. (2023). Recent insights into the use of antagonistic yeasts for sustainable biomanagement of postharvest pathogenic and mycotoxigenic fungi in fruits with their prevention strategies against mycotoxins. *Journal of Agricultural and Food Chemistry, 71*(26), 9923–9950. https://doi.org/10.1021/acs.jafc.3c00315

Pantelides, I. S., Christou, O., Tsolakidou, M.-D., Tsaltas, D., & Ioannou, N. (2015). Isolation, identification, and *in vitro* screening of grapevine yeasts for the control of black aspergilli on grapes. *Biological Control, 88,* 46–53. https://doi.org/10.1016/j.biocontrol.2015.04.021

Porras-Alfaro, A., & Bayman, P. (2011). Hidden fungi, emergent properties: Endophytes and microbiomes. *Annual Review of Phytopathology, 49,* 291–315. https://doi.org/10.1146/annurev-phyto-080508-081831

Sarver, E., González-Morelo, K. J., Christensen, K. G., Lefevers, H. M., & Corbin, K. R. (2025). Phyllosphere synthetic microbial communities: a new frontier in plant protection. *BMC Plant Biology, 25*(1), 949. https://doi.org/10.1186/s12870-025-06935-7

Sivakumar, N., Sathishkumar, R., Selvakumar, G., Shyamkumar, R., & Arjunekumar, K. (2020). Phyllospheric microbiomes: Diversity, ecological significance, and biotechnological applications. In *Plant microbiomes for sustainable agriculture* (pp. 113–172). Springer.

Sohrabi, R., Paasch, B. C., Liber, J. A., & He, S. Y. (2023). Phyllosphere microbiome. *Annual Review of Plant Biology, 74*(1), 539–568. https://doi.org/10.1146/annurev-arplant-102820-032704

Stone, J. K. (1987). Initiation and development of latent infections by *Rhabdocline parkeri* on Douglas-fir. *Canadian Journal of Botany, 65*, 2614–2621. https://doi.org/10.1139/b87-35

Sumbula, V., Kurian, P. S., Girija, D., & Cherian, K. A. (2022). Impact of foliar application of fungicides on tomato leaf fungal community structure revealed by metagenomic analysis. *Folia Microbiologica, 67*(1), 103–108. https://doi.org/10.1007/s12223-021-00920-x

Teixidó, N., Usall, J., Magan, N., & Viñas, I. (1999). Microbial population dynamics on Golden Delicious apples from bud to harvest and effect of fungicide applications. *Annals of Applied Biology, 134*, 109–116. https://doi.org/10.1111/j.1744-7348.1999.tb05241.x

Thomas, G., Kay, W. T., & Fones, H. N. (2024). Life on a leaf: The epiphyte-to-pathogen continuum and interplay in the phyllosphere. *BMC Biology*, *22*(1), 168. https://doi.org/10.1186/s12915-024-01967-1

Tryfinopoulou, P., Chourdaki, A., Nychas, G. J. E., & Panagou, E. Z. (2020). Competitive yeast action against *Aspergillus carbonarius* growth and ochratoxin A production. *International Journal of Food Microbiology, 317*, 108460. https://doi.org/10.1016/j.ijfoodmicro.2019.108460

Vorholt, J. A. (2012). Microbial life in the phyllosphere. *Nature Reviews Microbiology, 10*, 828–840. https://doi.org/10.1038/nrmicro2910

Wu, P. H., Chang, H. X., & Shen, Y. M. (2023). Effects of synthetic and environmentally friendly fungicides on powdery mildew management and the phyllosphere microbiome of cucumber. *PLOS One, 18*(3), e0282809. https://doi.org/10.1371/journal.pone.0282809

Zarraonaindia, I., Owens, S. M., Weisenhorn, P., West, K., Hampton-Marcell, J., Lax, S., Bokulich, N. A., Mills, D. A., Martin, G., Taghavi, S., Lelie, D., & Gilbert J. A. (2015). The soil microbiome influences grapevine-associated microbiota. *mBio, 6*, e02527–14. https://doi.org/10.1128/mBio.02527-14

INVESTIGATION OF MORPHOLOGICAL, PHYSIOLOGICAL AND AGRONOMIC CHARACTERICTICS OF TRITICUM SPELTA AND TRITICUM MACHA HEXAPLOID WHEAT SPECIES

Büşra İrem ÖZTEKIN

Eskişehir Osmangazi University, Agricultural Faculty, Field Crops Department

Prof. Dr. İmren KUTLU

Eskişehir Osmangazi University, Agricultural Faculty, Field Crops Department

ABSTRACT

Triticum spelta and *Triticum macha* are among the ancient cultivated wheat species and differ significantly from modern wheat species in terms of their morphological and physiological diversity, spike structure and adaptability. While *T. spelta* is generally a tall plant height, glume-like elongated spikes with low processing yields, *T. macha* is shorter, has a distinctive compact spike morphology, and is particularly prevalent in the Caucasus. This diversity results in significant differences between the two species in spike and flag leaf morphology, yield components, and some physiological traits, making them valuable genetic resources for breeding studies. In this study, 19 *T. spelta* and 28 *T. macha* accessions were evaluated for their morphological, physiological, and agronomic characteristics. The study aimed to examine the variation of the mentioned traits in two wheat species and to reveal the relationships between these variables using descriptive statistics and principal component analysis (PCA). Descriptive statistics revealed a wide variation in spike traits, flag leaf measurements, physiological traits, and yield components in both species. High variability (CV 37–55%) was observed, particularly in grain yield and biological yield. Mean spike length and flag leaf morphology were higher in *T. spelta*, while mean spikelet fertility, grain number per spike and flag leaf chlorophyll content were higher in *T. macha*. PCA results on *T. spelta* accessions revealed that the first two components explained 50.2% of the total variance, while the first five explained 79.3% where the eigenvalue is greater than 1. Variables related to yield components such as spike length, spike weight, grain weight per spike, grain number per spike, and flag leaf area in PC1 carried high positive loadings. PC2 was associated with flag leaf width and length and physiological indicators. In *T. spelta*, yield components and flag leaf morphology accumulate variance along two separate axes. In the PCA results for *T. macha* accessions, the first two components explained 49.7% of the total variance, while the first six explained 83.9% with greater than 1 eigenvalue. PC1 again showed a strong relationship with spike traits and yield components. PC2 was determined by flag leaf width, length, area, and physiological traits. Furthermore, in PC6, the flag leaf chlorophyll content variable was found to be a single, a unique discriminating variable in *T. macha* with a high loading value. In conclusion, PCA demonstrated that yield-related spike components and flag leaf morphology were clearly separated along different axes in both wheat species. These findings provide valuable insights into the selection of high-yielding traits in breeding programs. The pronounced differences between *T. spelta* and *T. macha* further highlight the strong influence of genetic background on morphological and physiological variation.

Keywords: Chlorophyll Content, NDVI, Spike Characteristics, Grain Yield, Leaf Morphology.

INTRODUCTION

Triticum aestivum L. is hexaploid form of wheat and one of the most globally cultivated crop as a staple food in numerous countries (Tadesse et al., 2019). Ancient subspecies within the primary gene pool of hexaploid wheat, especially spelt forms such as T. *macha* and T. *spelta* can be considered valuable genetic materials for new and potentially advantageous alleles. Ancient spelt wheats constitute an alternative source of genetic diversity that has been lost during the intensification of modern agriculture and breeding processes (Fu, 2015). Hexaploid spelt wheats exhibit significant variations in spike architecture, including spike shape, density, and grain form (Fan et al., 2019).

T. macha is the primitive hexaploid ancestor of other spelt forms and endemic to Georgia (Bedoshvili et al., 2021). Although *T. macha* is a spelt variety, its spikelets are not as densely arranged as those of other spelt wheat varieties. *T. macha* is hypothesized to be the ancestor of soft wheat varieties, transforming into modern bread wheat through human-induced selection due to its easy threshing and strong rachis characteristics (Jorjadze et al., 2014). In *T. macha*, the stems typically range from 40 to 100 cm in height, excluding the spikes, thin-walled or thick, hollow, and rarely hairy. The leaf blade is 8–32 cm × 8–12 mm, hairless or sparsely hairy, erect in young plants, drooping when mature; green or gray-green in color. Spikes are 7–12 cm long, erect or slightly inclined, moderately dense or sparse, awned or awnless, and white, red or blue-gray. The rachis (spike axis) is brittle, so the spikelet splits into two parts after threshing. The spikelets remain attached to the rachis joint (Feldman and Levy, 2023).

T. spelta has long been cultivated mainly in southwestern Germany, the valleys of the Austrian Alps, Switzerland, and a few other regions in Europe (Grausgruber, 2018). *T. spelta* stalks are erect, stiff, 60–120 cm tall excluding the heads, hairy or hairless, hollow, and thin-walled. The leaf sheaths are sparsely hairy or hairless; the auricles are very large, curved, fringed, and long-hairy. The leaf blades are 30–60 cm long, hairless or sparsely hairy, dark green and narrow in young plants, and pale greenish-yellow and broader in older stems. The spikes are quite long (10–15 cm), sparse (lax), straight or slightly curved, and may be white, red, gray-blue, or black-blue in color; they are distinctly pointed and awned or awnless. Each spike contains 16–22 spikelets, which are usually distinctly separated from each other on the axis. The rachis is flat and smooth; the rachis joints are semi-brittle and break easily under pressure (during threshing). Spikelets are oval and 12–16 mm long, solitary at the nodes, and hairy or haieless. The uppermost spikelet is fertile and positioned perpendicular to the plane of the lateral spikelets. In each spikelet, those in the middle of the spike carry 2 grains, while those at the base and tip are usually single-grained. The two glumes of each spikelet are similar in length, 8–12 mm, and may be white, yellow, red, brown, or black-blue. The glumes are shorter than the spikelet and may be bristly or bristle-free. The grains are reddish, 7–10 mm long, with a hard endosperm and pointed at both ends. The apex is covered with a white tuft of hairs and is tightly enclosed by the palea-lemma, forming a glume-like structure. The grain groove is shallow. The thousand-grain weight is 50–58 g (Feldman and Levy, 2023).

Both *T. macha* and *T. spelta* are gaining renewed interest today due to the increasing demand for healthy and diverse products in nutrition (Longin et al., 2023). Compared to bread wheat, they have superior agronomic performance under low-input conditions or challenging ecological environments. Therefore, they are highly suitable species for marginal areas and organic production systems (Konvalina et al., 2014; Magistrali et al., 2020). Furthermore, *T. macha* and *T. spelta* have significant genetic variation in many agronomic traits and disease resistance. Therefore, they are important genetic resources widely used in wheat breeding programs (Longin and Würschum, 2014; Wang et al., 2024).

Scientific studies on *T. macha* and *T. spelta* are limited and most involve a one-sided approach. These varieties are known as grains with high protein content and relatively low demands on growing conditions. Their ability to grow even in nutrient-poor mountain soils is a significant advantage. Furthermore, when provided with adequate mineral nutrition, they do not tend to shed grain after heading, eliminating the need for growth regulators. Their high resistance to heavy rainfall and excessive moisture during the tillering stage, their reduced susceptibility to fungal diseases due to their spelt structures, and their ability to germinate with their glume are among their notable characteristics. For these reasons, *T. macha* and *T. spelta* are becoming an increasingly important focus of interest for both researchers and farmers. As they are valuable genetic resources for breeding studies and for inclusion in agricultural production for different purposes, this study comprehensively examined the morphological, physiological, and agronomic characteristics of *T. macha* and *T. spelta*.

MATERIALS and METHODS

The experiment included 28 *Triticum macha* and 19 *Triticum spelta* wheat genotypes obtained from the USDA gene bank as plant material. Table 1 presents a comprehensive overview of the wheat genotypes utilized in this study.

The soil in the experimental field had a considerable amount of lime (7.2%) and a low organic matter content (2.3%). The pH level of the soil was 7.8, indicating a mild alkaline and non-saline nature. Clay, in particular, was identified as the predominant soil texture class. During the trial year, the mean temperature was 9.9°C, the mean humidity was 65.9%, and the total precipitation was 208.5 mm.

The seeds of wheat were sowed in rows that were one meter in length, with a spacing of 30 cm between rows and 5 cm within each row. The fixed fertilizer dose applied to the plants was 120 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1}, with all phosphorus applied at planting and half of the nitrogen applied at planting and the other half during the tillering period. Two supplementary irrigations were performed during the stem elongation and flowering periods.

The flag leaf area was determined by measuring the flag leaf width and length with a ruler and then multiplying by a factor of 0.75 according to the method of Kalayci et al. (1998). Flag leaf chlorophyll content was measured during the heading stage using a chlorophyll meter called “Spectrum Field Scout CM 1000.” An infrared thermometer was used to measure canopy temperature. Spectral reflectance from the canopy expressed as NDVI was measured using the GreenSeeker active optical sensor. Red (656 nm) and near-infrared (774 nm) self-illumination systems are built within the sensor. More red light is absorbed, and NIR light is largely reflected by a healthy plant.

The harvesting of plants that had reached full maturity was conducted through manual selection of the plants in the designated plots. The harvested spikes of plants whose biological performance was being measured were threshed by being compressed between plates covered with a rough rubber surface to separate the grains from their husks.

Table 1. List of hexaploid wheat genotypes used in the study

Genotype	Plant ID	Plant name	Collected From	Genoty	Plant ID	Plant name	Collected From
M1	PI 278660	Gen-2708	United Kingdom	SP1	PI 225271	Gen-85	Iran
M3	PI 355508	69Z5.187	Former, Soviet Union	SP2	PI 225295	Gen-109	Iran
M4	PI 355509	69Z5.188	Former, Soviet Union	SP3	PI 306550	Gen-2943	Romania
M6	PI 355511	69Z5.190	Sankt-Peterburg, Russian	SP4	PI 306551	Gen-2944	Romania
M7	PI 355512	69Z5.191	Former, Soviet Union	SP5	PI306552	Gen-2945	Romania
M8	PI 355513	69Z5.192	Former, Soviet Union	SP7	PI 306555	Gen-2948	Romania
M9	PI 355514	69Z5.193	Switzerland	SP10	CItr14138	CI 14138	Unknown
M10	PI 361862	DN-2378	Denmark	SP12	PI 295059	Deutchland	Bulgaria
M11	PI 428148	G1260	Stavropol'skij kraj, Russian	SP13	PI 221402	Fuchsii	Serbia
M13	PI 428177	G524	Uppsala län, Sweden	SP16	PI 295060	Hinducusch	Bulgaria
M16	PI 675002	GE.2013-15	Samtskhe-Javakheti, Georgia	SP17	PI 295062	Italien	Bulgaria
M17	PI675003	GE.2013-16	Samtskhe-Javakheti, Georgia	SP19	PI 591904	Liestal 11	Bulgaria
M18	PI 675004	GE.2013-17	Samtskhe-Javakheti, Georgia	SP20	PI 591903	Muri 6	Germany
M19	PI 295057	Gruzia	Bulgaria	SP21	PI 591901	Rotenburg 10	Niedersachsen, Germany
M20	PI 572908	H Tri 13595/89	Rach'a-Lechkhumi-Kvemo	SP23	PI 591894	Ruefenach 6	Germany
M21	PI 611470	H Tri 13601/87	Rach'a-Lechkhumi-Kvemo	SP24	PI 591902	Steiners Roter	Germany
M22	PI 572911	H Tri 13613/87	Imereti, Georgia	SP25	PI 295061	Ungarn-1	Bulgaria
M23	PI 572913	H Tri 13614/89	Imereti, Georgia	SP26	PI 295063	Ungarn-2	Bulgaria
M24	PI 572912	H Tri 13615/87	Imereti, Georgia	SP29	PI 591899	White Spelt	England, United Kingdom
M25	PI 542466	H86-708	Oregon, United States				
M26	PI 272554	I-1-2710	Pest, Hungary				
M27	PI 290507	I-1-2710	Pest, Hungary				
M28	PI 272555	I-1-3544	Pest, Hungary				
M29	PI 352466	Letshchumicum	Former, Soviet Union				
M30	PI 572906	WIR 28168	Georgia				
M31	PI 572907	WIR 28214	Georgia				
M32	PI 572905	WIR 29576	Georgia				
M33	PI 323436	Unknown	Wien, Austria				

The following metrics were recorded for each five plant in each parcel after harvest: spike length (cm), the number of spikelets per spike, the number of grains per spike, the total weight of grains per spike (g), the number of grains per spikelet, the spike density, and the spike index. Spike density (SD) and spike index (SI) were calculated as follows: The first ratio, SD, is calculated by dividing the number of spikelets by the length of the spike. The second ratio, SI, is determined by dividing the spike weight by the grain weight per spike.

The biological yield and grain yield of the plants harvested from each plot were determined in grams, and the harvest index was calculated as a percentage by dividing the grain yield by the biological yield.

The mean, minimum, and maximum values are displayed using boxplots, while descriptive statistics including variance, coefficient of variation, kurtosis, and skewness were calculated

using the Minitab 16 statistical software. Furthermore, a principal component analysis (PCA) based on the correlation matrix was applied to determine the relationships among the 17 examined features. The first five and six factors with eigenvalues greater than 1.0 were considered effective for interpreting the results. The first two components, which contained the majority of the variability, were presented as bi-plot arrangements of the following: *T. macha*, *T. spelta*, and all genotypes evaluated together and the examined traits.

RESULTS AND DISCUSSION

The morphology of flag leaves, including their width, length, and area, is a critical factor in determining the plant's photosynthetic capacity and, consequently, the final wheat yield (Zanella et al. 2023). Modifying the structure of flag leaves to maximize photosynthetic assimilation during the grain-filling stage is a desirable objective for wheat breeding programs. Various photosynthetic component traits, including flag leaf morphology, have demonstrated genetic variation despite their quantitative nature and have been consistently heritable. This renders them suitable for phenotypic selection, a process that is imperative for the breeding of superior wheat varieties (Poland 2015). The descriptive statistics concerning the morphological and physiological characteristics of the flag leaf examined in the study are presented in Table 2 and Figure 1. The descriptive statistics of the characteristics indicated a significant variation in the differences between *T. macha* and T. *spelta*. The flag leaf width of *T. macha* exhibited a more heterogeneous distribution, characterized by high variance and CV values, and a more expansive box structure. Genotypes such as M29 and M10 were particularly noteworthy for their elevated values, while *T. spelta* demonstrates a more constrained variation. As illustrated in Table 2, *T. spelta* had high variance in flag leaf length, a finding corroborated by Figure 2, which identified SP1 and SP19 as notable examples of long-leaved individuals. In the flag leaf area variable, *T. macha* presented higher variance and CV, and Figure 2 demonstrated that genotypes such as M7 and M28 broadened the distribution.

Selecting genotypes with a large flag leaf area is a sound approach due to its positive contribution to yield. However, in flag leaf area-based breeding programs, large leaves should be prioritized in regions without water limitations, while narrow leaves should be selected for arid environments. Genotypes with smaller flag leaf areas have better tolerance to drought and heat, so they should be considered. *T. macha* had a wider variation in flag leaf area, and there was a high probability of finding genotypes suitable for all conditions. Given that *T. spelta* comprises individuals with relatively narrower flag leaf areas, narrow-leaved genotypes can be selected for arid and hot areas.

Table 2. Descriptive statistics of the physiological characteristics examined in the study

	Variance			CoefVar			Skewness			Kurtosis		
Variable	*T. macha*	*T. spelta*	*All*	*T. macha*	*T. spelta*	*All*	*T. macha*	*T. spelta*	*All*	*T. macha*	*T. spelta*	*All*
Flag leaf width	0.05	0.02	0.05	13.79	8.90	13.12	-0.01	0.07	0.42	-0.30	0.81	0.03
Flag leaf length	9.25	15.33	15.12	11.42	12.84	13.79	0.45	-0.68	0.20	0.68	0.56	-0.48
Flag leaf area	53.23	27.88	42.39	21.28	14.97	18.77	0.20	-0.17	0.06	-1.29	-0.19	-1.01
Flag leaf chlorophyll index	4104.2	5976.4	5468.7	13.17	17.88	15.91	-0.80	-0.04	-0.51	0.00	-0.70	-0.60
Canopy temperature	0.13	0.12	0.65	2.34	2.06	5.09	0.06	-0.35	0.27	0.92	0.65	-1.28
NDVI	0.02	0.02	0.02	14.75	18.20	16.03	-1.30	-2.10	-1.70	1.12	4.81	3.00

This study revealed significant physiological differences between *T. macha* and *T. spelta* species based on findings obtained from flag leaf chlorophyll index, canopy temperature, and NDVI values. The literature indicates that flag leaf chlorophyll index is a strong indicator of photosynthetic capacity and carbon assimilation during the grain filling period (Noor et al., 2022). It is known that genotypes with high chlorophyll content have more stable photosynthetic activity both under optimal conditions and under stress. Chlorophyll content reflects the plant's photosynthetic efficiency and nitrogen use efficiency; high chlorophyll levels have been reported to be positively correlated with yield, especially under well-watered conditions (Ahmad et al., 2022; An et al., 2022; Sorwar Jahan et al., 2025). In our study, the fact that *T. macha* exhibited a wider variation in chlorophyll index and stood out with high-value genotypes such as M29 and M21 indicates that this species has different physiological strategies in terms of photosynthetic capacity (Figure 1). In contrast, although the variance was high in *T. spelta*, the distribution remains narrower, suggesting that this species exhibits a more homogeneous structure in terms of chlorophyll (Table 2).

Canopy temperature is widely regarded as one of the most sensitive indicators of drought stress, given its direct correlation with the plant's water status and stomatal behavior (Pinter et al., 1990). The findings of this study suggest that the low variation in canopy temperature values within species indicates that the population generally utilizes similar water use strategies. However, when all genotypes are evaluated collectively, high variance and variation coefficients indicate high interspecies variability, suggesting significant differences in canopy temperature between the two species (Table 1). However, the observation that *T. macha* displayed a lower canopy temperature distribution compared to *T. spelta* in Figure 1 suggested the existence of drought- and heat-tolerant genotypes within this species, thereby indicating potential candidates for selection. M6 and M25 stand out as particularly prominent genotypes.

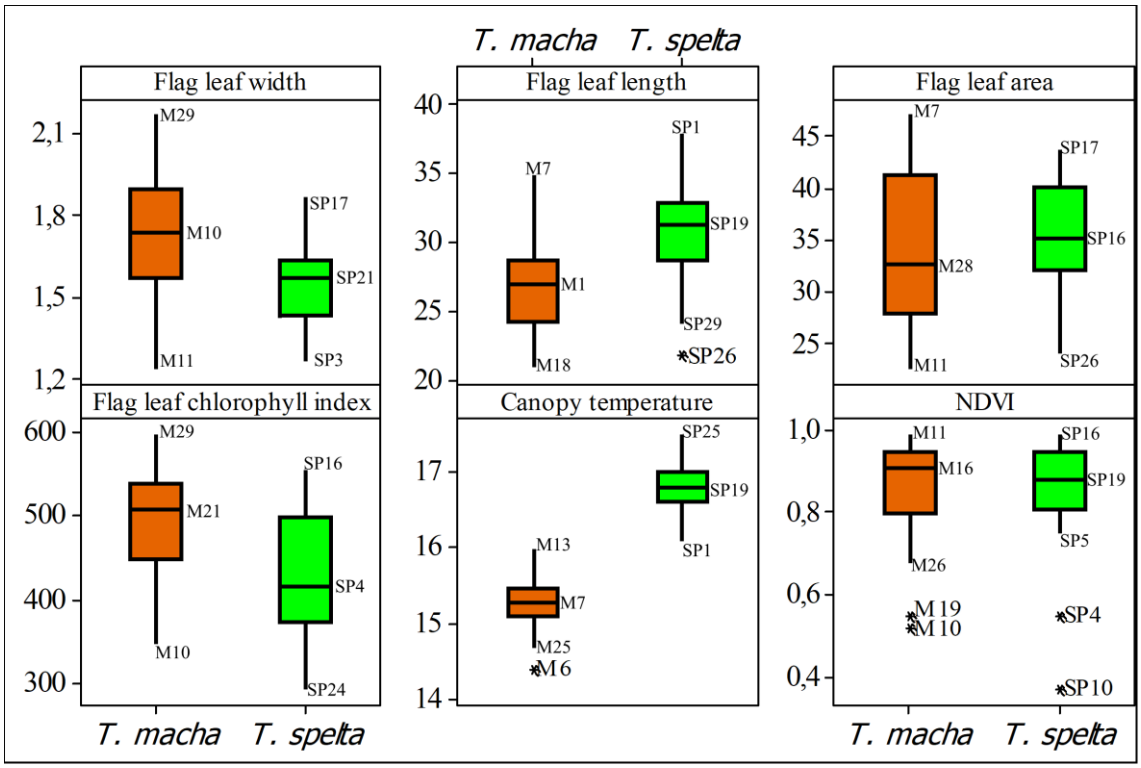


Figure 1. Minimum, maximum and mean values of the physiological characteristics examined in the study

NDVI values, the extent of green tissue, the biomass level, and overall physiological vitality in plants are critical factors for estimating yield (Hassan et al., 2019; Qiu et al., 2022). In this study, the wide NDVI variation observed in *T. spelta* reflects different levels of stress tolerance within the species. Moreover, the observation that certain genotypes with notably low NDVI values also manifest other stress indicators, such as low chlorophyll or high canopy temperature, reinforces the significance of NDVI as a comprehensive indicator of physiological stress. The low variance in NDVI values between the two species indicated that vegetative development is generally homogeneous (Table 2). However, the higher negative skewness and more pronounced extreme values in *T. spelta* indicated that the species possesses genotypes that may respond more variably to stress conditions. *T. spelta* exhibited distinctive characteristics in NDVI values, characterized by high skewness and extreme kurtosis. The boxplot graph demonstrated that the distinct low values of SP4 and SP10 corroborated this statistical finding (Figure 1).

Grain yield per spike is determined by the number of spikelets per spike, the number of grains per spike and/or spikelet, and grain size. On the other hand, grain yield per spike is calculated by the number of grains per spike, grain weight, and the number of spikes per area. The thousand-grain weight and number of grains per spike are significantly influenced by spikelet number, grain weight, and number of grains per spikelet (Philipp et al., 2018). These traits are directly associated with the genetic composition of wheat and is used in the identification of varieties. In this study, *T. macha* and *T. spelta* genotypes were compared in terms of spike morphology and yield components; variance, coefficient of variation, skewness, and kurtosis values (Table 3) were evaluated, and the maximum, minimum, mean, and range of the values were presented as boxplot graphs (Figure 2). A comparison of the genotypes of *T. macha* and *T. spelta* revealed that these two species exhibited distinctly different distributions in terms of spike architecture and yield components.

Table 3. Descriptive statistics of the spike characteristics examined in the study

	Variance			CoefVar			Skewness			Kurtosis		
	T. macha	T. spelta	All	T. macha	T. spelta	All	T. macha	T. spelta	All	T. macha	T. spelta	All
Spike length	4.70	4.85	6.36	20.59	16.72	21.75	0.84	-0.96	0.13	-0.41	2.00	-1.09
Spike weight	0.18	0.44	0.29	17.95	30.00	23.16	0.45	0.34	0.15	0.11	-0.15	0.19
Spikelet number per spike	16.95	5.79	17.73	17.42	12.74	19.39	-0.03	-0.68	0.40	-0.54	1.33	-0.25
Grain number per spike	84.85	37.46	97.85	20.47	18.35	24.55	-0.36	-1.39	0.06	0.08	1.40	-0.13
Grain number per spikelet	0.10	0.05	0.08	16.21	12.81	15.53	-0.77	0.40	-0.26	1.79	0.12	0.77
Grain weight per spike	0.08	0.11	0.09	20.26	24.14	21.70	0.88	-0.34	0.23	1.48	-0.94	0.39
Spike density	0.37	0.02	0.42	26.18	9.44	32.77	-0.37	0.25	0.56	-1.25	-0.61	-1.30
Spike index	55.70	92.23	71.18	12.53	15.32	13.87	0.78	2.20	1.63	1.34	7.24	5.31

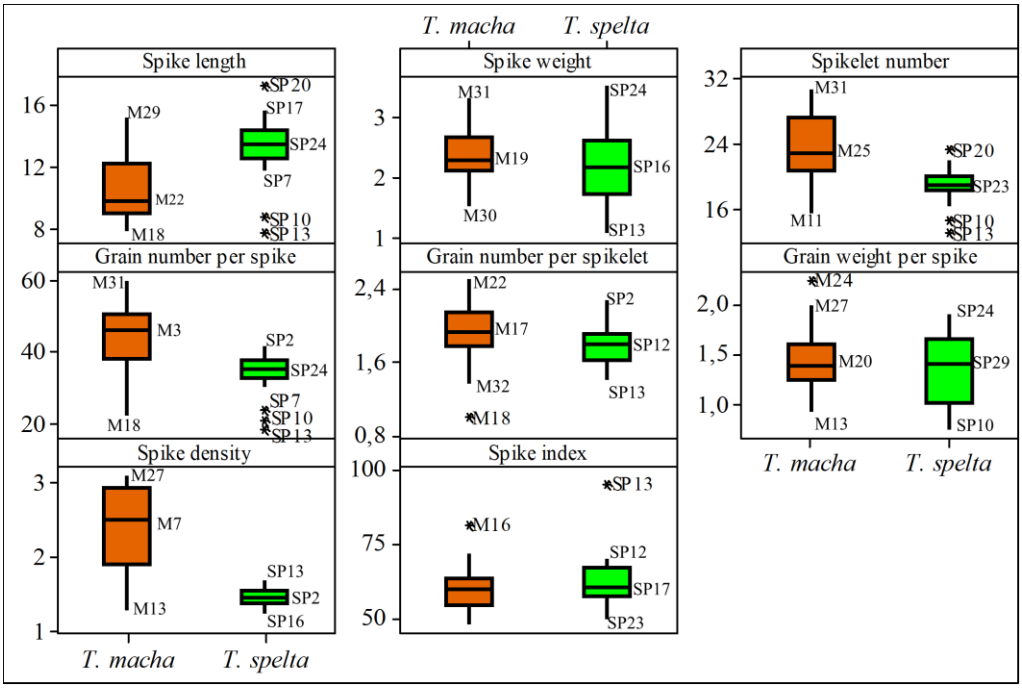


Figure 2. Minimum, maximum and mean values of the spike characteristics examined in the study

The boxplot graphs demonstrated that *T. spelta* achieves higher values, particularly in spike length and spike weight, while *T. macha* exhibited a wider range of variation in traits such as grain and spikelet number per spike (Figure 2). Descriptive statistics supported these differences; *T. macha* had a more heterogeneous population structure with higher variance and skewness-kurtosis values closer to a normal distribution for most traits, while *T. spelta* had extremely low variance and a highly stable structure for the spike density trait, and a structure with high variance, extreme skewness, and extreme values for the spike index trait (Table 3). In *T. spelta*, negative skewness in spike length and weight indicated a homogeneous structure away from low values, while in *T. macha*, positive skewness or near-symmetric distributions revealed a wider genetic variation. The higher variance evidenced by *T. macha* genotypes in traits such as spikelet number per spike, grain number per spike, and spike density confirms that this species originates from a more polymorphic population with greater genetic mixing, as reported by Barabaschi et al. (2025). Conversely, in the *T. spelta*, more limited and compressed distribution in certain traits suggests a more stable morphological structure in the hulled form (Szewczyk, 2013). The results indicated that *T. macha* had a more heterogeneous genetic structure, while *T. spelta* had a genetic structure that varies based on traits but was quite stable in some morphological characters.

T. macha is characterized by abundant leaf mass and robust stems, and it tolerates excessive moisture well (Samadashvili, 2024). *T. spelta*, on the other hand, is popular because of its good tolerance to growing conditions and its ability to withstand natural and climatic environmental factors, allowing it to be grown without excessive use of plant protection products. *T. spelta* can yield stable crops without strict adherence to production technology and can be a great alternative to soft wheat (Babenko et al., 2018). Despite the reported positive characteristics and their satisfactory biological yield, their production is limited due to low grain yields. Significant differences were observed between *T. macha* and *T. spelta* genotypes in terms of biological yield, grain yield, and harvest index. The variance in biological yield was quite high in *T. macha* (101,385) and much lower in *T. spelta* (34,814). Furthermore, the CV value of *T. macha* was 45.7%, which was more than twice that of *T. spelta* (Table 4).

Table 4. Descriptive statistics of the yield characteristics examined in the study

	Variance			CoefVar			Skewness			Kurtosis		
	T. macha	T. spelta	All	T. macha	T. spelta	All	T. macha	T. spelta	All	T. macha	T. spelta	All
Biological Yield	101385.6	34814.0	89975.9	45.70	19.47	37.38	-0.04	-0.70	-0.54	-0.53	1.02	-0.27
Grain yield	4430.1	3178.8	4487.24	66.49	37.28	55.46	1.51	0.62	0.83	4.08	0.71	1.29
Harvest index	18.66	18.46	18.96	31.19	27.48	29.88	0.18	-0.06	0.07	0.07	-0.94	-0.46

T. spelta had higher median values in biological yield and exhibited a narrower distribution among genotypes, while *T. macha* showed wider variance and a more heterogeneous structure (Figure 3). These findings indicated that *T. macha* had a more variable population structure in terms of biomass production. A similar difference was noticeable in grain yield; while *T. spelta* showed higher yield levels in the boxplot, the Table 4 results revealed that *T. macha* had much higher variance (4.430) and skewness (1.51) in this trait. The high positive skewness in *T.*

macha's grain yield indicated that some genotypes had extremely low yield values, whereas *T. spelta* showed a more balanced distribution. In terms of harvest index, the two species showed a more similar variation structure; the fact that the variances of both species were very close to each other (18.66–18.46) and the skewness is close to zero indicated that this trait was more stable between species. However, the boxplot graph showed that *T. spelta* tended to have slightly higher values in the harvest index.

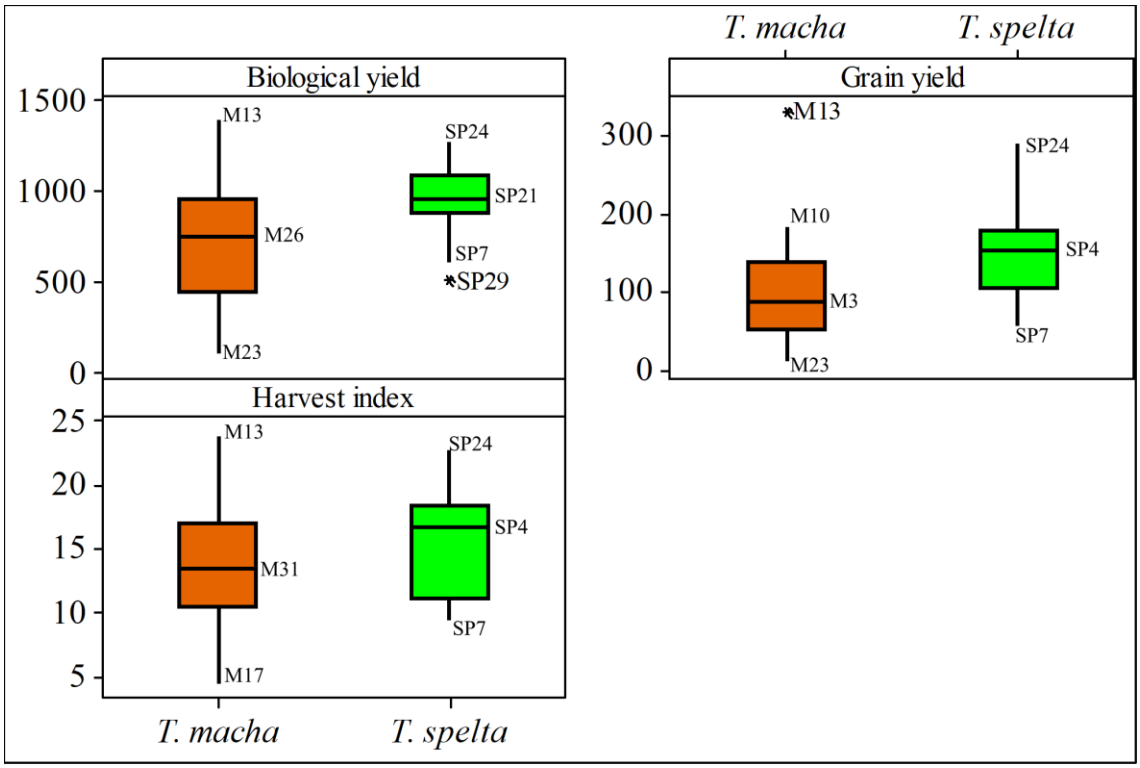


Figure 3. Minimum, maximum and mean values of the yield characteristics examined in the study

Overall, these results revealed that *T. macha* had a population structure with wider variation and extreme values in terms of biomass and grain yield, while *T. spelta* exhibited a more stable, higher biological and grain yield and a more homogeneous character in terms of distribution.

The findings revealed that *T. macha* was more heterogeneous and diverse, while *T. spelta* had a more stable structure in terms of certain morphological characteristics; these differences also affect the potential use of the species in breeding programs. In general, *T. spelta* offers a more advantageous structure in terms of characteristics that enhance physiological performance, while *T. macha* is characterized by more heterogeneous morphological variation. These results revealed that the difference between the species was not morphological but was mainly evident in physiological productivity indicators. Consequently, these distinct differences in the distribution characteristics of the two species stem from differences in evolutionary history, breeding history, reproductive system, and selection pressures.

The PCA loadings of *T. macha* and *T. spelta* genotypes revealed that the relationships between the morphological and physiological traits of the two species show fundamentally similar trends, but that some characters created species-specific differentiation (Table 5). In both species, the PC1 axis largely represented spike morphology and yield components; traits such as spike weight (SW), grain number per spike (GNS), grain weight per spike (GWS), flag leaf area (FLA), and spikelet number (SN) were the variables that gave the highest positive loadings

to PC1. This indicated that, regardless of species differences, the variation in basic morphological structures related to yield determines the first component.

Table 5. Factor loadings obtained from the principal component analysis

	T. macha						T. spelta					All genotypes					
Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC1	PC2	PC3	PC4	PC5	PC6
SL	0,10	0,42	0,22	0,01	0,08	0,12	0,38	0,09	-0,18	-0,12	0,02	-0.18	-0.34	-0.03	-0.40	-0.09	0.02
SW	0,39	-0,03	-0,04	0,20	0,27	-0,05	0,37	-0,04	0,17	0,24	0,02	0.25	-0.34	0.11	-0.10	-0.02	-0.37
SN	0,31	-0,27	-0,23	0,12	0,08	0,13	0,34	0,17	-0,11	-0,12	0,29	0.39	-0.05	0.22	0.07	0.00	-0.17
GNS	0,38	-0,11	0,11	-0,25	0,14	0,01	0,39	0,03	-0,13	-0,21	0,06	0.40	-0.14	0.02	-0.15	0.16	0.16
GNSp	0,14	0,16	0,42	-0,47	0,15	-0,13	0,28	-0,12	-0,09	-0,21	-0,16	0.16	-0.17	-0.21	-0.40	0.23	0.45
GWS	0,38	-0,17	-0,05	-0,18	0,15	-0,13	0,37	-0,09	0,21	0,02	-0,12	0.27	-0.31	0.02	0.03	0.35	-0.25
SD	0,12	-0,44	-0,31	0,05	-0,04	0,04	-0,28	0,04	0,19	0,06	0,35	0.36	0.20	0.17	0.30	0.06	-0.11
SI	0,04	-0,27	0,01	-0,63	-0,17	-0,09	-0,22	-0,06	0,14	-0,43	-0,42	-0.05	0.10	-0.19	0.29	0.72	0.19
FLW	0,34	0,17	-0,04	0,14	-0,32	0,09	0,18	-0,19	-0,25	0,37	0,02	0.25	-0.26	-0.03	0.10	-0.30	0.21
FLL	0,31	0,06	0,22	0,15	0,09	-0,00	-0,03	-0,44	0,27	-0,14	0,04	-0.10	-0.28	-0.42	0.26	0.08	-0.11
FLA	0,39	0,14	0,09	0,16	-0,16	0,05	0,08	-0,49	0,08	0,11	0,04	0.12	-0.38	-0.32	0.25	-0.14	0.06
FLCI	-0,04	-0,06	-0,11	-0,21	0,24	0,83	-0,02	0,13	-0,10	-0,45	0,55	0.15	0.15	0.25	-0.11	-0.00	0.45
CT	-0,16	0,15	-0,22	-0,11	0,54	-0,16	-0,04	0,34	-0,13	0,46	-0,11	-0.37	-0.12	0.02	-0.00	0.12	-0.24
NDVI	-0,07	-0,05	0,39	0,16	0,26	0,33	0,09	0,18	-0,17	-0,21	-0,49	0.01	0.06	-0.09	-0.51	0.24	-0.26
BY	0,11	0,36	-0,27	-0,24	-0,33	0,19	0,21	-0,05	0,51	0,01	0,03	-0.20	-0.35	0.16	0.19	-0.01	0.29
GY	0,08	0,39	-0,38	-0,13	-0,03	0,07	0,12	0,29	0,51	0,05	-0,03	-0.22	-0.30	0.42	0.12	0.09	0.14
HI	0,08	0,23	-0,34	0,00	0,40	-0,19	0,04	0,45	0,29	-0,02	-0,04	-0.13	-0.17	0.53	-0.01	0.25	-0.05

In *T. macha*, PC2 and PC3 appear to be more related to flag leaf traits (FLW, FLL, FLA) and spike density (SD) and plant structure, while in *T. spelta*, flag leaf traits gave the highest negative loadings to the PC2 axis, and PC3 represented yield components (BY, GY, GWS) more. This situation showed that in *T. spelta* genotypes, the variation in leaf traits was clearly reflected in the second component, while yield traits shaped the third component.

In both species, PC4 and PC5 were related to physiological variables representing the environmental response. In particular, spike index (SI), canopy temperature (CT), and NDVI showed high load values on these axes. In *T. spelta*, SI occupied high negative loadings in both PC4 and PC5, indicating that it was an important discriminating factor in the variance structure of spike yield in this species. In *T. macha*, the very high positive loading (0.83) of FLCI on PC6 indicated that the chlorophyll index formed an independent axis of variation in this species.

When all genotypes were analyzed together, morphological traits such as GNS, SN, SD, and FLA were again dominant on the PC1 axis, while leaf traits and spike density stood out on PC2, and yield traits and harvest index stood out on PC3. The high loadings of NDVI and CT, particularly on PC4 and PC5, indicated that physiological responses contribute to the variance structure explained in later components, independent of species differences. In the joint analysis of all genotypes, these distinctions were more balanced, with morphological-yield components forming the primary source of variation and physiological indicators forming the secondary source of variation.

PCA distributions showed that a large portion of the variation in both *T. macha* and *T. spelta* genotypes was explained by spike morphology and yield components (Figure 4). In the *T. macha* genotypes in the upper panel, grain number per spike (GNS), grain weight per spike (GWS), spikelet number (SN), spike weight (SW), and flag leaf area (FLA) contributed most strongly to the PC1 (29%) axis. The fact that the arrows of these traits point in the same direction indicated that high-yield components in *T. macha* genotypes increase alongside similar morphological traits. In contrast, the PC2 (21%) axis was shaped more by physiological variables such as canopy temperature (CT), NDVI, and FLCI. The distribution of *T. macha* genotypes showed that some genotypes, particularly M13, M14, and M18, differ from others in terms of physiological responses.

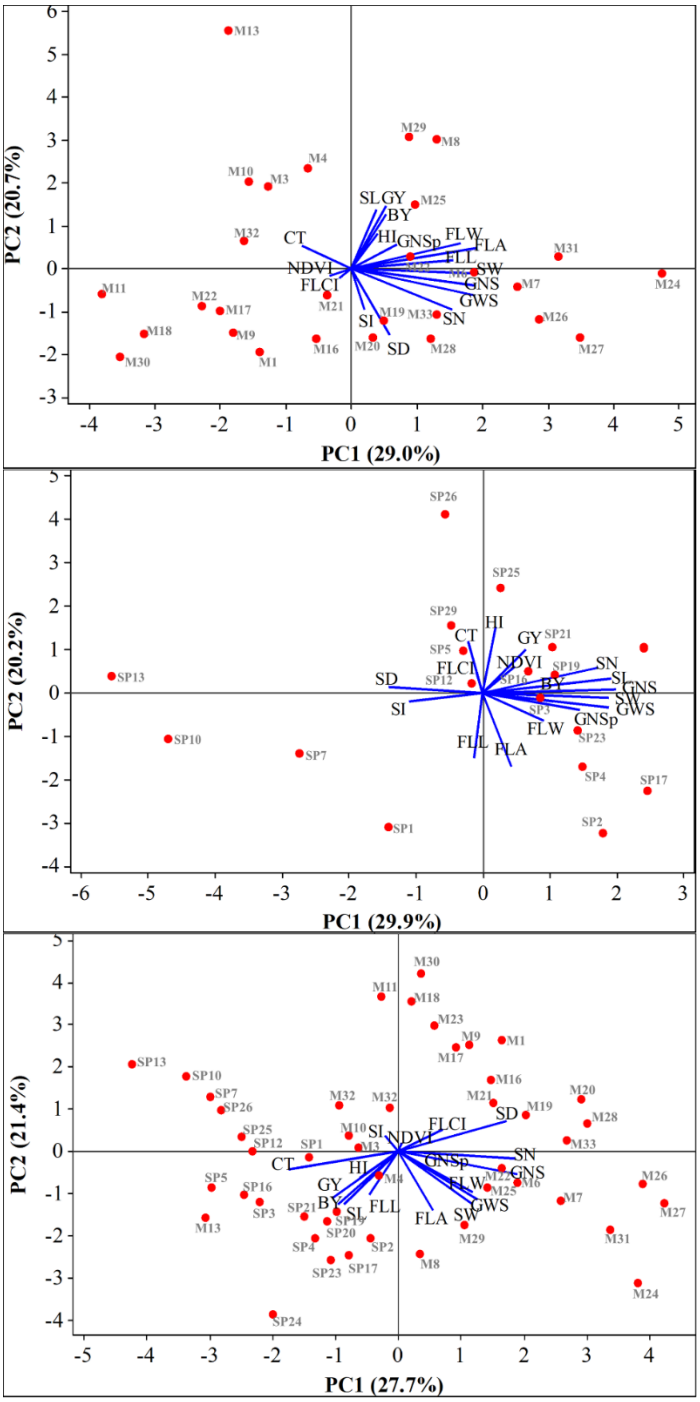


Figure 3. Bi-plot graph obtained from PCA analysis

The distribution of *T. spelta* genotypes in the middle panel showed that PC1 (29.9%) again represents yield and spike structure, but in *T. spelta*, PC2 (22.2%) was more clearly related to flag leaf traits (FLW, FLL, FLA) and spike density (SD). In particular, the negative positioning of genotypes such as SP7, SP10, and SP13 on the PC1 axis indicated that these genotypes had low values for yield and spike components; conversely, the positive clustering of genotypes such as SP24 and SP21 indicated that high yield components were concentrated in a narrower group of genotypes in *T. spelta*. Furthermore, the shorter arrows of physiological variables in *T. spelta* genotypes indicated that these traits did not determine the variation structure as strongly as *T. macha*.

In the lower panel, when all genotypes were evaluated together, it was seen that the PC1 (27.7%) axis again represented yield components, while the PC2 (21.4%) axis was determined by both flag leaf characteristics and physiological indicators. When examining the distribution of the two types of genotypes in the field, it was seen that *T. macha* genotypes generally cluster closer to the center of the axis, while *T. spelta* genotypes showed a wider spread. This supported the idea that variation in *T. spelta* was particularly high in traits such as flag leaf characteristics and spike density. Furthermore, the fact that the spearhead lengths of variables related to yield, such as GNS, GWS, SW, and SN, were highest in all genotypes revealed that these traits explained the largest portion of the total variance in the study and were the fundamental determinants of inter-genotypic distinctiveness.

Overall, when the three PCA graphs were evaluated together, *T. macha* genotypes exhibited a more homogeneous variation structure, while *T. spelta* genotypes showed a wider distribution, particularly in morphological traits. In contrast, yield components remained the main source of variation in both species. Physiological variables (CT, NDVI, FLCI) more strongly separated the variation structure in *T. macha*, while their effects were more limited in *T. spelta*. This indicated that the species had different strategies in their physiological responses and yield determinants.

CONCLUSION

This study revealed that *T. macha* and *T. spelta* genotypes exhibited distinct variation patterns in terms of morphological, physiological, and yield components. In general, *T. macha* showed wider variance, more balanced distributions, and a more heterogeneous population structure in spike architecture (SN, GNS, GWS, SD), flag leaf morphology (FLW, FLA), and some yield components. In contrast, *T. spelta* had higher average values and better performance in traits that particularly increased yield and physiological capacity, such as spike length, spike weight, grain yield, flag leaf length, chlorophyll index, and NDVI. *T. spelta*'s low variance in some traits (e.g., spike density, canopy temperature) indicated a more stable morphological structure; however, high skewness and kurtosis values in other traits suggested yield potential in certain genotypes.

PCA analyses revealed that the main determinants of variation in both species were spike structure and yield components; however, physiological variables (NDVI, CT, FLCI) more strongly separated variation in *T. macha*, while remaining more limited in *T. spelta*. Genotype distributions showed that *T. macha* clustered in a more compact genetic variation space, while *T. spelta* exhibited a wider spread in yield and physiological traits, clearly revealing superior-performing genotypes. In terms of yield, *T. spelta* genotypes generally had higher biological and grain yields, while *T. macha* genotypes showed a more variable structure at the species level, even though they included high-yielding individuals.

When all findings were evaluated together, *T. macha* stands out as an important resource for increasing genetic diversity and morphological variation in breeding studies, while *T. spelta* offers valuable genotypes, particularly in terms of its potential to improve photosynthetic capacity and yield components. The complementary characteristics of these two species are strategically important for creating a robust genetic pool in modern wheat breeding, both in terms of adaptation and yield.

REFERENCES

Ahmad, A., Aslam, Z., Javed, T., Hussain, S., Raza, A., Shabbir, R., ... & Tauseef, M. (2022). Screening of wheat (Triticum aestivum L.) genotypes for drought tolerance through agronomic and physiological response. Agronomy, 12(2), 287.

An, Q., Li, C., Li, H., Zheng, Q., Li, B., & Li, Z. (2022). An analysis of the genetic relation between photosynthesis and yield-related traits in wheat. Agriculture, 12(4), 560.

Babenko, L. M., Hospodarenko, H. M., Rozhkov, R. V., Pariy, Y. F., Pariy, M. F., Babenko, A. V., & Kosakivska, I. V. (2018). Triticum spelta: Origin, biological characteristics and perspectives for use in breeding and agriculture. Regulatory Mechanisms in Biosystems, 9(2), 250-257.

Barabaschi, D., Volante, A., Faccioli, P., Povesi, A., Tagliaferri, I., Mazzucotelli, E., & Cattivelli, L. (2025). Ancient diversity of Triticum aestivum subspecies as source of novel loci for bread wheat improvement. Frontiers in Plant Science, 16, 1536991.

Bedoshvili, D., Mosulishvili, M., Chkhutiashvili, G., Maisaia, I., Ustiashvili, N., & Merabishvili, M. (2021). Diversity and local use of wheat in Georgia. The Journal of Nature Studies-Annals of Agrarian Science, 19(2).

Fan, X., Cui, F., Ji, J., Zhang, W., Zhao, X., Liu, J., ... & Li, J. (2019). Dissection of pleiotropic QTL regions controlling wheat spike characteristics under different nitrogen treatments using traditional and conditional QTL mapping. Frontiers in plant science, 10, 187.

Feldman, M., & Levy, A. A. (2023). Triticum L. In Wheat Evolution and Domestication (pp. 365-526). Cham: Springer International Publishing.

Fu, Y. B. (2015). Understanding crop genetic diversity under modern plant breeding. Theoretical and Applied Genetics, 128(11), 2131-2142.

Grausgruber, H. (2018). “Sorting the wheat from the chaff: Comments on the spelt [:wheat] discussion,” in Proceedings of a Congress. Proceedings of the 68. Tagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs 2017. (Tulln: Universität für Bodenkultur Wien), 69–74.

Hassan, M. A., Yang, M., Rasheed, A., Yang, G., Reynolds, M., Xia, X., ... & He, Z. (2019). A rapid monitoring of NDVI across the wheat growth cycle for grain yield prediction using a multi-spectral UAV platform. Plant science, 282, 95-103.

Jorjadze, M., Berishvili, T., & Shatberashvili, E. (2014). The ancient wheats of Georgia and their traditional use in the southern part of the country. Emirates Journal of Food & Agriculture (EJFA), 26(2).

Konvalina, P., Stehno, Z., Capouchová, I., Zechner, E., Berger, S., Grausgruber, H., ... & Moudrý Sr, J. (2014). Differences in grain/straw ratio, protein content and yield in landraces and modern varieties of different wheat species under organic farming. Euphytica, 199(1), 31-40.

Longin, C. F. H., & Würschum, T. (2014). Genetic variability, heritability and correlation among agronomic and disease resistance traits in a diversity panel and elite breeding material of spelt wheat. Plant breeding, 133(4), 459-464.

Longin, C. F. H., Afzal, M., Pfannstiel, J., Bertsche, U., Melzer, T., Ruf, A., ... & Rodehutscord, M. (2023). Mineral and phytic acid content as well as phytase activity in flours and breads made from different wheat species. International Journal of Molecular Sciences, 24(3), 2770.

Magistrali, A., Vavera, R., Janovska, D., Rempelos, L., Cakmak, I., Leifert, C., ... & Bilsborrow, P. (2020). Evaluating the effect of agronomic management practices on the performance of differing spelt (Triticum spelta) cultivars in contrasting environments. Field Crops Research, 255, 107869.

Noor, H., Sun, M., Algwaiz, H. I., Sher, A., Fiaz, S., Attia, K. A., ... & Gao, Z. (2022). Chlorophyll fluorescence and grain filling characteristic of wheat (Triticum aestivum L.) in response to nitrogen application level. Molecular Biology Reports, 49(7), 7157-7172.

Philipp, N., Weichert, H., Bohra, U., Weschke, W., Schulthess, A. W., & Weber, H. (2018). Grain number and grain yield distribution along the spike remain stable despite breeding for high yield in winter wheat. PloS one, 13(10), e0205452.

Pinter Jr, P. J., Zipoli, G., Reginato, R. J., Jackson, R. D., Idso, S. B., & Hohman, J. P. (1990). Canopy temperature as an indicator of differential water use and yield performance among wheat cultivars. Agricultural Water Management, 18(1), 35-48.

Poland, J. (2015). Breeding-assisted genomics. Current opinion in plant biology, 24, 119-124. https://doi.org/10.1016/j.pbi.2015.02.009

Qiu, Q., Zhang, M., Wang, N., Qiu, R., & Miao, Y. (2022). Plant Phenotyping. In Soil and Crop Sensing for Precision Crop Production (pp. 185-250). Cham: Springer International Publishing.

Samadashvili, T. (2024). The Role of Georgian Endemic Wheat Species in Biodiversity of Wheat. Georgian Scientists, 6(3), 221-224.

Sorwar Jahan, M. A. H., Azam, M. G., Mohi-Ud-Din, M., Rohman, M. M., Begum, F., Haque Khan, M. H., ... & Hossain, A. (2025). Agronomic parameters and drought tolerance indices of bread wheat genotypes as influenced by well-watered and water deficit conditions. BMC Plant Biology, 25(1), 1-21.

Szewczyk, B. F. (2013). The influence of morphological features of spelt wheat (Triticum aestivum ssp. spelta) and common wheat (Triticum aestivum ssp. vulgare) varieties on the competitiveness against weeds in organic farming system. Journal of Food, Agriculture & Environment, 11(1), 416-421.

Tadesse, W., Sanchez-Garcia, M., Assefa, S. G., Amri, A., Bishaw, Z., Ogbonnaya, F. C., & Baum, M. (2019). Genetic gains in wheat breeding and its role in feeding the world. Crop Breeding, Genetics and Genomics, 1(1).

Wang, Y., Wang, Z., Chen, Y., Lan, T., Wang, X., Liu, G., ... & Peng, H. (2024). Genomic insights into the origin and evolution of spelt (Triticum spelta L.) as a valuable gene pool for modern wheat breeding. Plant Commun 5: 100883.

Zanella, C. M., Rotondo, M., McCormick-Barnes, C., Mellers, G., Corsi, B., Berry, S., ... & Cockram, J. (2023). Longer epidermal cells underlie a quantitative source of variation in wheat flag leaf size. New Phytologist, 237(5), 1558-1573.https://doi.org/10.1111/nph.18676

VIRTUAL REALITY AS A TOOL FOR FARMER TRAINING IN BIODIVERSITY-FRIENDLY PRACTICES

Oluwadamilola Peace AGOI

Federal University of Agriculture Abeokuta, Ogun Nigeria.

Moses Adeolu AGOI

Lagos State University of Education, Lagos Nigeria.

ORCID ID: 0000-0002-8910-2876

Samuel Olayiwola AJAGA

Lagos State University of Education, Lagos Nigeria.

Oluwanifemi Opeyemi AGOI

Obafemi Awolowo University, Osun Nigeria.

Abstract

Virtual Reality (VR) is increasingly recognized as a transformative tool for training farmers in sustainable and biodiversity-friendly agricultural practices. As global agriculture faces mounting challenges, including biodiversity loss, soil degradation, and climate variability, there is an urgent need for training approaches that can effectively convey complex ecological interactions and sustainable management strategies. VR provides a unique opportunity to immerse farmers in highly realistic, interactive environments where they can explore, observe, and practice biodiversity-enhancing techniques without incurring real-world risks. By situating learners within simulated farm landscapes, VR facilitates experiential learning that traditional extension methods often struggle to achieve. This paper examines how VR-based training environments can strengthen farmers' understanding of ecological processes, improve decision-making, and encourage behavioural change toward biodiversity-positive practices. It draws on recent advancements such as VR-enabled decision-support systems for climate-smart farm planning, immersive agricultural education frameworks like the VRFARM model, and VR applications in ecosystem visualization and landscape ecology. These developments demonstrate VR's potential to help farmers visualize long-term ecological outcomes, such as habitat restoration, species interactions, and carbon sequestration, while comparing the economic implications of different land-use choices. We further propose a mixed-methods evaluation framework that integrates quantitative learning assessments, behavioural intention measures, and qualitative reflections to assess VR's effectiveness as a training tool. Despite its promise, VR adoption faces several constraints. High hardware costs, limited technological infrastructure in rural areas, and digital literacy gaps can restrict equitable access to immersive training. Moreover, ensuring ecological accuracy in virtual simulations requires interdisciplinary collaboration and continuous updates. Ultimately, VR represents a promising yet evolving approach to promoting biodiversity-friendly agriculture. While early evidence

highlights its potential to enhance ecological literacy and lower barriers to knowledge transfer, further research is needed to evaluate long-term impacts, improve accessibility, and tailor VR solutions to diverse farming contexts.

Keywords: Biodiversity, Immersive Learning, Virtual Reality.

INTRODUCTION

Agriculture today faces unprecedented pressure to balance productivity with ecological sustainability as global environmental challenges intensify. Biodiversity loss, declining soil fertility, and accelerating climate change continue to undermine the stability and long-term viability of conventional farming systems. These challenges highlight the urgent need to transition toward agricultural models that protect and restore ecological functions while supporting food security. Achieving this transition requires equipping farmers with practical knowledge, technical skills, and adaptive capacities necessary for implementing biodiversity-friendly practices such as agroforestry, intercropping, cover cropping, conservation agriculture, and regenerative soil management. However, traditional agricultural extension approaches, typically dependent on field demonstrations, printed manuals, and one-off workshops, often struggle to meet current demands. Limitations such as high or recurrent costs, difficulties reaching remote communities, constraints on scalability, and the risks associated with experimenting in real fields can impede widespread adoption of sustainable innovations. Virtual Reality (VR) offers a promising technological alternative that addresses many of these barriers. VR creates immersive, interactive learning environments in which farmers can visualize, model, and experiment with ecological practices without incurring the real-world costs, uncertainties, or potential losses associated with trial-and-error learning. Through carefully designed simulations, farmers can observe how biodiversity-enhancing interventions, such as planting native tree belts, adjusting crop rotations, or establishing pollinator habitats, affect ecological dynamics and long-term productivity. VR has also enabled the development of advanced “decision-support environments” that integrate biophysical and economic models, allowing users to simulate different land-use scenarios and immediately compare their ecological and financial outcomes. This capability helps farmers better understand trade-offs, evaluate risk, and make more informed decisions regarding biodiversity-sensitive management. In addition to decision support, VR-based educational frameworks such as the VRFARM model demonstrate the pedagogical value of immersive technologies in agriculture. The VRFARM framework emphasizes facilitation, application, reflection, and measurement, showing how immersive learning strengthens agricultural literacy, engagement, and awareness, particularly among learners with limited formal education or technical experience. By enabling learners to explore virtual representations of farms, ecosystems, and species interactions, VR fosters a deeper ecological understanding that traditional extension methods often fail to deliver. Against this background, this paper investigates the emerging role of VR as a training tool for promoting

biodiversity-friendly agricultural practices. We provide a comprehensive review of existing literature, outline methodological approaches for evaluating VR-based training interventions, examine the realized and potential impacts of immersive learning on farmers' ecological knowledge and behaviour, and identify critical gaps that future research must address.

LITERATURE REVIEW

Greig et al. (2024) make a substantial contribution to VR-based agricultural education by introducing the VRFARM framework, an integrated, structured model for designing and assessing virtual reality (VR) learning experiences in the classroom. The VRFARM model comprises four interrelated components: Facilitation, Application, Reflection, and Measurement, each mapping onto and expanding Biggs' classic "3P" (presage, process, product) pedagogical model (Biggs, 2003). Specifically, "Presage" becomes Facilitation, emphasizing the role of student and teacher characteristics, the learning environment, and scaffolding of VR experiences; "Process" translates to Application, the direct engagement of learners in VR activities; and "Product" is reconceptualised as both Reflection (learners revisiting and internalizing their experiences) and Measurement (systematic evaluation of learning outcomes). In their empirical and methodological analysis, Greig et al. (2024) detail how each component can be operationalized in an agricultural education setting. For example, under Facilitation, they examine teacher readiness, student prior agricultural literacy, and the infrastructure required (hardware, software, and instructional design). For Application, they propose immersive virtual field trips, interactive simulations, and skill-based VR modules, which enable students to "walk through" production environments, simulate farm management, or visualize ecological processes (Greig et al., 2024). Reflection involves guided debriefs, peer discussion, and journaling, while Measurement uses both qualitative methods (interviews, focus groups) and quantitative assessments (pre-/post-tests) to gauge changes in agricultural literacy, engagement, and awareness (Greig et al., 2024). This structured framework is essential: the authors argue that VR's introduction into curricula without systematic scaffolding risks superficial novelty without meaningful learning. By applying mixed-methods interventions, VRFARM allows educators not only to deliver immersive experiences but also to rigorously evaluate their pedagogical impact, ensuring that VR translates into real comprehension and behavioural intent. In a complementary but distinct direction, Chatterjee et al. (2025) explore how VR simulation can be tailored for farmer training rather than formal classroom settings. Their study covers multiple agricultural domains, including crop simulation, livestock management, and even supply chain logistics, showing that VR can bolster experiential competencies among farmers. According to their findings, farmers using VR were better able to visualize complex interactions, anticipate outcomes of different management strategies, and make more informed decisions. These simulations help in internalizing ecological trade-offs, for instance, between productivity and conservation, thereby strengthening their capacity to adopt eco-friendly farming practices. A particularly compelling application of VR lies in decision-support systems. Lasseur et al. (2023) pioneered a VR-based decision-support tool developed in Unreal Engine that links realistic farm visualizations with biophysical and economic models. In their proof-of-concept study on a 400-hectare pastoral farm in New Zealand, farmers can "enter" a virtual representation of their land and experiment by planting different tree species in various locations. The system dynamically computes carbon sequestration, profitability, establishment costs, and aesthetic outcomes, allowing users to compare strategies side by side (Lasseur et al., 2023). This immersive modeling offers a tangible way to plan biodiversity-enhancing interventions, such as planting native species corridors or agroforestry buffers, while optimizing for both ecological and financial goals. Beyond farm planning, VR has also been harnessed for ecological modeling and environmental

education more broadly. Landscape ecologists have developed immersive virtual ecosystems that represent endangered habitats, such as the Box Gum Grassy Woodland, to communicate reference ecological conditions and species interactions to land managers. Users report that these simulations feel "believable" and help them grasp spatial and ecological relationships in ways that static diagrams or text cannot. Such immersive experiences can deepen understanding of ecosystem structure, connectivity, and function. In the realm of broader conservation education, VR360 environments are increasingly employed to teach about ecosystem dynamics, indigenous knowledge, and cultural conservation. For instance, Herwidiah et al. (2022) developed a VR360 platform designed to communicate indigenous environmental wisdom and biodiversity concepts to broader audiences. Participants navigate virtual landscapes, observe species behaviours, and learn traditional ecological narratives, fostering greater ecological empathy and conservation awareness. Looking beyond VR, the broader category of Extended Reality (XR), which includes Augmented Reality (AR) and Mixed Reality (MR), has considerable promise for sustainable farming education and practice. Naudé et al. (2024) proposed an XR-AgriEdu framework for higher education that emphasizes three core pillars: agricultural determinants, curriculum development, and facilitating conditions (e.g., infrastructure, instructor training). Their framework illustrates how XR can bridge the gap between theoretical agricultural science and real-world applications, especially for students who lack farm backgrounds. XR enables virtual field trips, overlaying soil-nutrient maps, or holographic visualizations of crop growth, making complex agricultural concepts accessible and experiential (Naudé et al., 2024). Moreover, XR can support *in-field decision-support* and precision farming: as noted by recent systematic reviews, XR tools can visualize soil moisture, nutrient distributions, and forecasted crop outcomes, enabling farmers to overlay data in real time and simulate sustainable scenarios like intercropping or agroforestry in a risk-free, virtual setting (Bigonah et al. 2025). Such immersive decision-support has the potential to accelerate adoption of biodiversity-friendly practices. However, despite these advances, the literature also points to persistent challenges. Hardware costs, especially for high-end VR headsets or powerful computers, remain a major barrier (Bigonah et al., 2025; Greig et al., 2024). In many rural or under-resourced farming communities, infrastructure limitations such as unreliable internet, limited electricity, or lack of technical support hinder deployment. Moreover, acceptability among farmers is not guaranteed: digital literacy, cultural perceptions, and trust in technology affect uptake (Chikene, Singisetti, & Pradhan, 2025). In their discussion, Greig et al. (2024) underscore the importance of teacher training, community buy-in, and equity considerations when implementing VR in educational or extension contexts. Finally, there is an emerging need for ongoing research to validate and refine these frameworks. Systematic reviews show that although XR technologies are proliferating in agriculture, evaluation of long-term learning outcomes, behavioural change, and ecological impact is still limited (Bigonah et al., 2025). Also, cross-cultural adaptation and inclusivity remain underexplored: how do VR and XR trainings translate in different geographical settings, socio-economic contexts, or linguistic backgrounds? Addressing these gaps will be crucial to scaling immersive technology interventions in biodiversity-friendly farming.

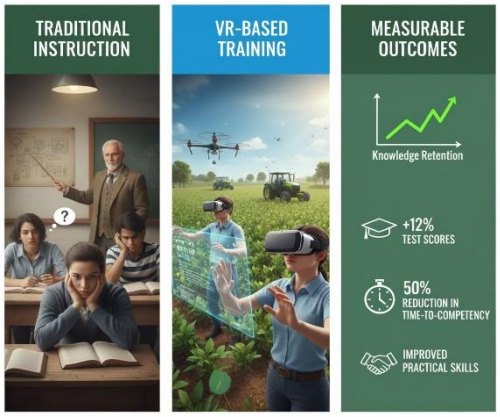
MATERIALS AND METHODS

To evaluate the effectiveness of VR-based farmer training in biodiversity-friendly practices, the study adopts a comprehensive methodological approach that begins with the design of immersive VR training scenarios using advanced game-engine platforms such as Unreal Engine to simulate realistic farm landscapes featuring agroforestry plots, native species corridors, and intercropping systems. These virtual environments integrate biophysical and economic models, including growth simulations, carbon sequestration estimates, and profitability analyses,

following the approach demonstrated by Lasseur et al. (2023), while participatory co-design with farmers, agronomists, and ecological experts ensures contextual relevance and ecological accuracy. The study recruits a diverse sample of farmers across multiple ecological zones and assigns participants to either a control group receiving traditional training or a treatment group receiving VR-based instruction. Evaluation follows a mixed-methods framework inspired by the VRFARM model (Greig et al., 2024), incorporating presage variables such as participant demographics, baseline ecological knowledge, and prior attitudes; process measures including VR interaction logs, time spent in modules, and decisions made during simulations; and product outcomes involving learning gains, shifts in attitudes, and intentions to adopt biodiversity-enhancing practices. Data collection includes reflective interviews and focus-group discussions, as well as quantitative pre- and post-tests of ecological literacy, decision-making ability, and sustainability adoption readiness. Analytical procedures combine statistical tests such as paired t-tests and ANOVA to assess changes over time with qualitative thematic analysis of narrative data, complemented by economic modeling of potential adoption scenarios to estimate real-world impacts. Ethical considerations guide the entire process, ensuring informed consent, data privacy, and sensitivity to participants' varying levels of digital literacy, while providing technical support and on boarding for those unfamiliar with VR technologies.

RESULTS AND DISCUSSION

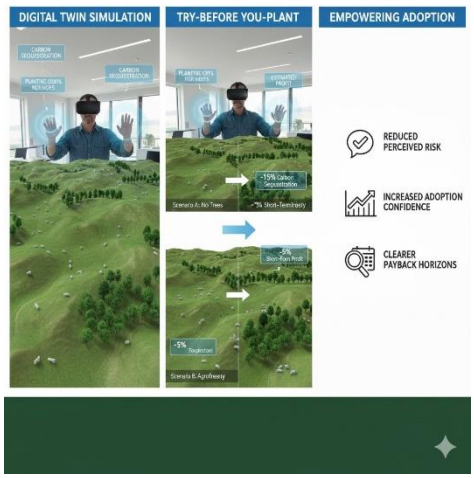
Learning Outcomes and Ecological Literacy



Building on prior studies, we anticipate that participants exposed to VR-based training will demonstrate substantially greater gains in ecological literacy than those receiving conventional instruction, and several empirical and evaluative reports bolster this expectation. Greig et al.'s VRFARM framework emphasizes not only immersive application but also structured facilitation, guided reflection, and rigorous measurement, creating the scaffolding necessary for VR experiences to translate into durable learning gains (Greig et al., 2024). Evidence from domain-specific VR training further supports measurable improvements: a controlled pilot at Poltava State Agrarian University found that students trained with a Unity-based VR simulator for tractor-plough setup scored higher on theoretical tests (mean = 3.60 vs. 3.36 for control) and made fewer critical mistakes during real-world procedures, demonstrating transfer from virtual practice to tangible performance (Kanivets et al., 2025). Large sectoral evaluations likewise report consistent improvements in engagement, retention, and test scores when VR replaces or supplements traditional training, Walmart and other industry adopters documented test-score improvements of roughly 10-15% in corporate training comparisons, and government reviews conclude that VR reduces time-to-competency while increasing accessibility (Australian Dept. of Agriculture review, 2020). Specifically for biodiversity and farm-planning education, Lasseur et al. (2023) demonstrated a geospatial VR "digital twin" that allows farmers to stand in a realistic 400-ha virtual landscape, plant different tree species in 30×30 m grid cells, and immediately inspect modelled carbon sequestration and profitability outcomes, an approach that operationalizes ecological concepts (habitat placement, connectivity, species choice) into decision tasks that learners can practice and iterate on without real-world costs (Lasseur et al., 2023). By converting complex ecological processes into manipulateable, visual scenarios, such systems scaffold understanding of species interactions,

edge effects, and ecosystem services in ways that static diagrams cannot. Systematic and scoping reviews of XR in agriculture and education report similar patterns: immersive systems excel at visualising spatial ecological relationships and at promoting active experimentation, both of which are strong predictors of deeper conceptual change and behavioural intention. Mechanisms explaining these gains include "presence" and embodied interaction, VR induces a sense of being in the environment which increases attentional focus and the salience of ecological feedback loops, plus the ability to repeat scenarios, receive immediate model-based feedback, and reflect in structured debriefs (components emphasized in VRFARM). Taken together, the peer-reviewed prototypes, controlled pilots, and sector reviews create a convergent empirical case: immersive VR training, if implemented within a deliberate pedagogical framework and supported with evaluation metrics, produces measurable improvements in ecological literacy, practical competence, and adoption readiness for biodiversity-friendly farming. Future trials should prioritize randomized designs with long-term follow-up to quantify retention, behavioural adoption, and on-farm biodiversity outcomes.

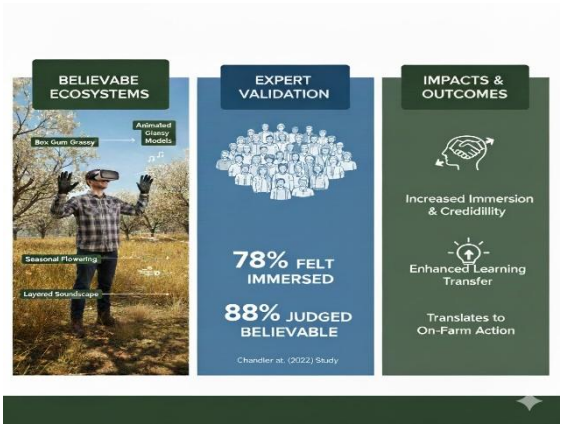
Decision-making and Adoption Intention



Embedding decision-support models within immersive VR environments gives farmers an unprecedented, practice-oriented way to see and weigh trade-offs between biodiversity outcomes and farm profitability, and emerging empirical work shows this capability can meaningfully reduce perceived risk and increase adoption confidence. For example, Lasseur et al. (2023) built a geospatial VR "digital twin" of a New Zealand pastoral farm that lets users place trees in a 30 × 30 m grid and instantly view modelled outputs such as carbon sequestration, establishment costs, and projected profitability; by converting abstract ecological functions into immediate, visible consequences, the tool turns strategic choices (where and what to plant) into repeatable experiments rather than one-time, risky investments. This "try-before-you-plant" affordance matters because perceived uncertainty and fear of loss are major barriers to on-farm adoption of biodiversity-friendly measures (e.g., agroforestry, native corridors). VR reduces that uncertainty by enabling rapid scenario iteration and side-by-side comparisons of outcomes under differing assumptions (growth rates, discounting, maintenance costs), which helps farmers internalize both short- and long-term trade-offs and better estimate payback horizons. Beyond intuitive reasoning, immersive systems also shape psychological drivers linked to adoption. Experimental and quasi-experimental studies in environmental VR show that high presence and embodied interaction increase risk salience and pro-environmental intent: participants exposed to immersive climate or biodiversity scenarios report greater perceived personal relevance, stronger emotional engagement, and higher willingness to adopt mitigation or conservation behaviours than those in non-immersive conditions (Santoso & Bailenson, 2024; Hurrell, 2024). Translating this to agriculture, a VR decision-support environment that visualizes both ecological gains (e.g., increased habitat area, connectivity, carbon sequestration) and economic impacts (e.g., net present value, opportunity cost) can thus simultaneously strengthen ecological literacy and reduce the psychological barrier that often prevents trial adoption. Empirical sector reports and pilot studies also suggest measurable practical benefits. Case studies of VR and XR training in agricultural and technical domains report improvements in confidence, faster time-to-competency, and greater inclination to try new techniques after

immersive training sessions (industry and university pilots summarized in systematic reviews). For instance, controlled pilots in vocational agricultural settings (tractor operation, agronomic decision modules) document higher post-test scores and fewer critical mistakes when learners had virtual rehearsal opportunities, indicating that virtual practice can transfer to safer real-world action. From a decision-support design perspective, the effectiveness of VR hinges on a few practical features: integration of credible, locally calibrated biophysical and economic models; transparent presentation of assumptions (growth rates, discount factors); the ability to run sensitivity analyses within the VR session; and structured debriefing that links virtual choices to on-farm implementation steps. Lasseur et al. highlight the importance of linking immersive visualization to robust underpinning models so that users receive trustworthy feedback rather than mere graphical impressions. Finally, macro-level analyses of digital agriculture show that when farmers perceive clear economic benefits and lower implementation risk, adoption rates increase, digital decision tools that make benefits and costs explicit therefore serve a dual role: they inform better decisions and act as a de-risking mechanism that increases uptake of biodiversity-friendly practices (Geng et al., 2024). Taken together, the current empirical literature supports the contention that VR decision-support, by making trade-offs visible, repeatable, and emotionally salient, can raise farmer confidence and accelerate the experimentation and adoption of biodiversity-positive land-use choices. Future research should prioritize randomized field trials that measure not only attitudinal shifts but actual on-farm adoption and ecological outcomes over multi-year horizons.

Ecological Validity and Realism



The success of VR as a tool for farmer training hinges critically on ecological realism, that is, how faithfully a virtual ecosystem reproduces the visual, spatial, temporal, and functional properties of the real landscape it represents. Empirical evaluations show this is not merely aesthetic: believable virtual ecosystems increase immersion, credibility, and the perceived usefulness of the tool among expert users and stakeholders, which in turn affects uptake, learning transfer, and the likelihood that virtual choices are translated into on-farm action. For example, Chandler et al. (2022) built a proof-of-concept virtual Box Gum Grassy Woodland and evaluated it with 27 domain experts (ecologists, land managers, policy practitioners). In that expert panel 21 of 27 participants (78%) reported feeling immersed in the VR scenes, and a striking 88% judged the simulation to be *believable* (Chandler et al., 2022). Participants specifically flagged features that supported believability, animated plant models, seasonally-accurate flowering, spatially varying light and shadow, and layered soundscapes (bird calls, wind), while also suggesting improvements (e.g., more understory heterogeneity and fauna) to increase ecological fidelity (Chandler et al., 2022). These concrete assessment numbers show that expert buy-in depends on careful ecological modelling, not just photorealism. Technical design choices materially affect realism and performance. Chandler et al. experimented with model creation approaches (artist-crafted 3D species models vs. LiDAR/photogrammetry) and concluded that carefully sculpted models often offer a pragmatic balance between botanical fidelity and rendering performance (Chandler et al., 2022). Similarly, Lasseur et al. (2023) emphasise that credible decision-support VR must be anchored in robust, locally calibrated biophysical and economic models so that the visual feedback users receive corresponds to

scientifically defensible outcomes. Their Unreal Engine prototype for a 400-ha New Zealand farm linked spatial NDVI layers, carbon accounting, and profitability calculations, enabling users to "stand in" a virtual farm and immediately see modelled carbon sequestration and profit implications when planting trees in 30×30 m grid cells (Lasseur et al., 2023). Lasseur et al. report that the tool helped reconcile farmers' tacit knowledge with scientific data, a critical function for trust and adoption (Lasseur et al., 2023). Landscape-scale realism also requires attention to spatial patterning and connectivity, core concerns of landscape ecology, because biodiversity outcomes (species movement, habitat patchiness, and edge effects) hinge on landscape configuration as much as on local species lists. Recent reviews of computational methods in landscape ecology stress that spatial resolution, connectivity metrics, and simulation models (e.g., neutral landscape generators, resistance surfaces) are central to predicting ecological processes and must feed VR models to make them ecologically meaningful (Hesselbarth et al., 2024). In practice, this means VR developers should integrate open-source landscape tools (e.g., NLMR, landscape metrics) or pre-processed remote-sensing layers so the virtual scene reflects real heterogeneity rather than uniform "green everywhere" textures (Hesselbarth et al., 2024). Given these empirical and methodological findings, good practice for maximizing ecological realism and usefulness includes: (1) co-design with local ecological experts (botanists, wildlife ecologists) and farmers to ensure species composition, structure, and management scenarios are locally relevant (Chandler et al., 2022); (2) use of multi-source spatial data (remote sensing, DEMs, soil maps) and transparent model assumptions (growth rates, species niches) so users can query and trust outputs (Lasseur et al., 2023); (3) iterative expert evaluation (heuristic testing, expert panels) to quantify believability and identify gaps, Chandler et al.'s expert trial is a model (78-88% immersion/believability metrics); and (4) performance-aware modelling that balances botanical accuracy with rendering efficiency (e.g., level-of-detail methods, selective fauna animations) to keep VR usable on accessible hardware (Chandler et al., 2022; Hesselbarth et al., 2024). Ultimately, ecological realism is not optional: it is the coupling mechanism that converts immersive experience into domain knowledge, managerial confidence, and, eventually, biodiversity-friendly decisions on the ground.

Implications for Extension and Policy

VR can meaningfully complement traditional extension services, particularly in remote and underserved regions, by offering scalable, low-risk, and repeatable training that augments, rather than replaces, human-led advisory systems. Immersive VR modules permit farmers to experience simulated management actions (e.g., planting agroforestry belts, installing riparian buffers, or trailing intercropping layouts) and immediately view modelled ecological and economic outcomes; this experiential "trial run" helps reduce perceived implementation risk and can accelerate willingness to experiment on-farm (Lasseur et al., 2023). Empirical evidence supports this claim: a recent PLOS ONE demonstration linked a VR decision-support "digital twin" to biophysical and carbon-accounting models for a 400-ha New Zealand pastoral property and found that the immersive tool aided farmers in reconciling tacit local knowledge with scientific model outputs, improving planning confidence and scenario comparison (Lasseur et al., 2023). Large institutional programs show VR and digital training have scale potential when integrated into extension networks. The FAO's digital-extension guidance and summary of virtual trainings demonstrates that centrally coordinated virtual training can reach thousands of practitioners efficiently: FAO reports training ~1,350 national-level staff from 118 countries through virtual training modalities during 2020-2024, illustrating how centralized digital delivery can rapidly disseminate technical content at scale and at low marginal cost per participant. Pilot studies of VR for extension content also provide favourable empirical outcomes: a pilot on VR 360° tours for manure and mortality management documented

statistically significant increases in awareness after viewing VR modules ($p < 0.0001$), with participants rating the format as engaging and likely to be recommended to peers, evidence that remote immersive media can improve technical understanding without in-person field visits. From a policy and delivery standpoint, several implementation models have emerged that governments and donors could support. Shared-resource VR hubs (community centres, district extension offices, or mobile VR vans) can lower hardware barriers by providing scheduled access points where farmers gather for facilitated sessions; FAO and development reviews note such hub-and-spoke models as effective for digital extension rollouts. Subsidies or cost-sharing for hardware and local facilitation, plus funding for locally calibrated content development, can further enhance equity and uptake: policy analyses on agricultural modernization emphasize that targeted subsidies for extension infrastructure and training often yield strong returns in adoption and productivity when paired with capacity building (JRC/World Bank reviews). Systematic reviews of XR in agriculture underscore both promise and caveats: XR/VR consistently improves engagement, retention, and skill rehearsal across agricultural and technical domains, but gaps remain in long-term impact evaluations and in accessible, low-cost hardware solutions suitable for rural deployment (Anastasiou et al., 2023). To maximize benefit, policy design should therefore combine (a) content subsidies and shared hubs to ensure equitable access, (b) capacity building for extension agents so they can facilitate VR debriefs and link virtual choices to on-farm steps (the pedagogical element crucial to the VRFARM model), and (c) monitoring & evaluation funding to measure behavioural adoption and ecological outcomes over multi-year horizons. When implemented this way, VR becomes a powerful multiplier for extension: scalable, pedagogically robust, and able to lower the economic and psychological barriers that often prevent farmers from trailing biodiversity-friendly practices.

CONCLUSION

Virtual Reality (VR) represents a highly promising and innovative pathway for strengthening farmer training in biodiversity-friendly agricultural practices. Through immersive, interactive environments linked to biophysical and economic models, VR enables farmers to engage directly with simulated ecosystems, experiment with alternative land-use strategies, and visualize both short- and long-term ecological outcomes. This experiential mode of learning helps demystify complex concepts such as habitat connectivity, species interactions, and ecosystem service provision, while simultaneously illustrating the economic trade-offs associated with different management choices. Evidence from educational research, including VRFARM applications, and VR-based decision-support systems demonstrates notable improvements in ecological literacy, learner engagement, and farmers' intention to adopt biodiversity-enhancing practices. These findings suggest that VR has the potential to transform conventional extension by lowering barriers to experimentation and fostering more informed, confident decision-making. Yet, several challenges must be addressed for VR to reach its full potential in biodiversity-positive farming. Issues of hardware cost, digital access, rural connectivity, and technical training can limit equitable participation, particularly in underserved farming communities. Furthermore, the effectiveness of VR tools depends heavily on their ecological realism and contextual adaptation, which requires interdisciplinary collaboration with local ecologists, agronomists, and farmers. Continuous evaluation is equally essential to ensure that VR interventions translate not only into knowledge gains but also into sustained behavioural changes and measurable on-farm biodiversity outcomes. With thoughtful design, inclusive implementation strategies, and long-term assessment, VR could become a powerful catalyst for scaling agro ecological practices, accelerating the adoption of biodiversity-friendly innovations, and strengthening conservation efforts within agricultural landscapes.

Future Research

Future research should prioritize longitudinal studies to evaluate whether farmers trained through VR actually adopt biodiversity-friendly practices and the resulting ecological impacts, such as changes in species richness and soil health over time. Investigations into access and equity are essential, including strategies to reduce cost barriers through shared VR hubs, mobile units, or low-cost hardware, as well as digital literacy interventions to support marginalized groups like women, older farmers, and low-income participants. Research should also focus on contextual adaptation by tailoring VR modules to diverse agro-ecological zones, cultural settings, and biodiversity priorities, assessing how these factors influence engagement and uptake. Technological innovation offers further opportunities, such as integrating VR with augmented and mixed reality for hybrid virtual–on-field training and incorporating real-time farm data from IoT and sensors to ensure immersive scenarios reflect current conditions. Finally, studies should examine economic and policy mechanisms that facilitate scaling VR-based training, including incentive structures, extension partnerships, public-private models, and cost-benefit analyses comparing VR approaches with conventional biodiversity training methods.

References

[1] Anastasiou, E., Balafoutis, A., & Fountas, S. (2023). Applications of extended reality (XR) in agriculture, livestock farming, and aquaculture: A review. *Smart Agricultural Technology, 3*, Article 100105. https://doi.org/10.1016/j.sag.2023.100105

[2] Anastasiou, E., et al. (2023). Applications of extended reality (XR) in agriculture: A review. *ScienceDirect*.

[3] Bigonah, M., Jamshidi, F., Pant, A., Poudel, S., et al. (2025). A systematic review of extended reality (XR) technologies in agriculture and related sectors (2022–2024). *IEEE Access*. Advance online publication. https://doi.org/10.1109/ACCESS.2025.3550891

[4] Chandler, T., Richards, A. E., Jenny, B., Dickson, F., Huang, J., Klippel, A., Neylan, M., Wang, F., & Prober, S. M. (2022). Immersive landscapes: Modelling ecosystem reference conditions in virtual reality. *Landscape Ecology, 37*, 1293-1309. https://doi.org/10.1007/s10980-021-01313-8

[5] Chatterjee, D., Sadhu, S., Mondal, D., & Kalindi, D. (2025). Use of virtual reality simulation practices for farmers training. *Madras Agricultural Journal*. https://doi.org/10.29321/MAJ.10.701159

[6] Chikene, H., Singisetti, V., & Pradhan, S. K. (2025). Revolutionising agriculture with augmented reality (AR) and virtual reality (VR). *NG Agriculture Insights, 1*(1), 44-46. https://doi.org/10.5281/zenodo.15570294

[7] Department of Agriculture, Water and the Environment (Australia). (2020). *Virtual reality to support FMD training* (Report). Australian Government.

[8] FAO. (2024). *Summary report: Virtual trainings 2020-2024 & guide on digital agricultural extension and advisory services*. Food and Agriculture Organization of the United Nations.

[9] Geng, W., et al. (2024). Digital technologies adoption and economic benefits in agriculture. *Sustainability, 16*(11), 4431. https://doi.org/10.3390/su16114431

[10] Greig, J. A., Colclasure, B., Rampold, S., & Ruth, T. (2024). Enhancing agricultural education through virtual reality: Facilitation, application, reflection, and measurement in the

classroom. *Advancements in Agricultural Development, 5*(2), 64-80. https://doi.org/10.37433/aad.v5i2.353

[11] Gunawardana, D., Wang, X., Mahdaviarab, A., McCubbins, O. P., Landaverde, R., & Liu, Z. (2023). Virtual reality videos for delivery of extension educational materials on manure and mortality management: A pilot study. *Preprints*. https://doi.org/10.20944/preprints202311.0601.v1

[12] Gupta, R. K. (2024). Revolutionizing agriculture: The magic of virtual reality (VR) and augmented reality (AR). *Farm Chronicle, 3*(8), 20-25.

[13] Gupta, S. K. (Ed.). (2025). *Exploring the impact of extended reality (XR) technologies on promoting environmental sustainability*. Springer. https://doi.org/10.1007/978-3-031-88013-1

[14] Hajj-Hassan, M., Chaker, R., & Cederqvist, A.-M. (2024). Environmental education: A systematic review on the use of digital tools for fostering sustainability awareness. *Sustainability, 16*(9), 3733. https://doi.org/10.3390/su16093733

[15] Herwidiah, I., et al. (2022). Development of a VR360 ecological system for learning indigenous cultures and environmental conservation. *Applied Sciences, 14*(22), Article 10582. https://doi.org/10.3390/app142210582

[16] Hesselbarth, M. H. K., Nowosad, J., de Flamingh, A., Simpkins, C. E., Jung, M., Gerber, G., & Bosch, M. (2024). Computational methods in landscape ecology. *Current Landscape Ecology Reports, 10*(2). https://doi.org/10.1007/s40823-024-00104-6

[17] Hurrell, C. (2024). Virtual reality facilitates pro-environmental behavioural change: Evidence from immersive interventions. *Environmental Education Research*. https://doi.org/10.1080/13504622.2024.2342942

[18] Kanivets, O. V., Kanivets, I. M., Pidhorna, S. V., Bilovod, O. I., & Burlaka, O. A. (2025). Design and validation of a virtual reality-based training program for student learning on tractor-plough setup. *CEUR Workshop Proceedings*.

[19] Lasseur, R., Laurenson, S., Ali, M., Loh, I., & Mackay, M. (2023). Designing profitable and climate-smart farms using virtual reality. *PLOS ONE, 18*(6), e0286723. https://doi.org/10.1371/journal.pone.0286723

[20] Naudé, D. H., Botha, B. S., Hugo, L., Jordaan, H., & Lombard, W. A. (2024). Extended reality in agricultural education: A framework for implementation. *Education Sciences, 14*(12), 1309. https://doi.org/10.3390/educsci14121309

[21] Parikh, et al. (2022). Greening the virtual city: Accelerating peer-to-peer learning in urban agriculture with virtual reality environments. *Cornell Chronicle*.

[22] Rishan Solutions. (2025). *XR for sustainable farming practices*. Rishan Digital.

[23] Santoso, M., & Bailenson, J. (2024). *Virtual reality experiences to promote environmental behaviour* (Technical report). Stanford Virtual Human Interaction Lab.

[24] World Bank. (2013). *Strengthening agricultural extension and advisory systems: Procedures and policy options* (Policy Research Working Paper). World Bank.

BEHAVIORS AND ATTITUDES OF ACADEMIC AND ADMINISTRATIVE STAFF AND UNIVERSITY STUDENTS TOWARDS DOGS

Hürü Ceyda TÜM

M.S. Scholar, Department of Pathology, Faculty of Veterinary Medicine, Erciyes University, Kayseri, Turkey.

(ORCID: 0009-0000-4138-6112)

Assoc. Prof. Dr. Davut BAYRAM

Advisor, Department of Animal Breeding and Husbandry Science, Faculty of Veterinary Medicine, Erciyes University, Kayseri, Turkey.

(ORCID: 0000-0003-1495-1248)

ABSTRACT

This research was conducted to evaluate the attitudes, behaviors, and ownership tendencies of academic and administrative staff and students in universities towards dogs through a holistic approach. The study aims to analyze the level of awareness regarding dogs, experiences of pet ownership, frequency of interaction with dogs, and attitudes towards the environments in which dogs live, within the axis of socio-demographic variables and psychological factors. This descriptive study was carried out using quantitative data collection techniques via face-to-face and online survey methods.

The study population comprises academic and administrative staff working at universities in Turkey, as well as undergraduates. The sample consists of 1,033 volunteer participants working and studying at eight universities located in different geographical regions, primarily Erciyes University (including Burdur Mehmet Akif Ersoy, Afyon Kocatepe, Aydın Adnan Menderes, Hatay Mustafa Kemal, Kafkas, Bursa Uludağ, and Selçuk University). The survey form used as the data collection tool consists of six main sections: demographic information, attitudes towards dogs, ownership and care, health, training and human-dog relationships, and dogs' reactions to environmental stimuli and social interaction needs.

The obtained data were analyzed using R 4.5.2 and JMP Pro 16.01 statistical software packages. In addition to descriptive statistics, Spearman correlation, chi-square tests, Cramér's V effect size analyses, and Kruskal-Wallis tests were used to examine the relationships between variables. Furthermore, multivariate logistic regression models were established to determine the factors defining dog ownership.

The findings indicate that participants generally exhibit an empathetic, sensitive, and welfare-oriented approach towards dogs. Variables such as gender, age, profession, income level, pet ownership, and psychological awareness were determined to have significant effects on attitudes. It was observed that female participants exhibited a more protective and empathetic approach towards dogs, whereas male participants displayed a more pragmatic and distant attitude; additionally, the love for animals was found to be stronger in younger individuals. Awareness regarding animal care and a professional approach were more prominent in

individuals with high income levels, while emotional attachment was more distinct in individuals with lower income levels. One of the most critical results of the study is that even individuals with high levels of knowledge can show behavioral inconsistencies in practice—a situation defined as the "knowledge-action gap"—and that application rates for procedures such as neutering remain low even among the educated segment.

“This research is summarized from thesis project number 13972, supported by the Erciyes University Research and Development Unit as a Master's thesis.”

Keywords: Animal Welfare, Attitude, Dog, Human-Animal Interaction, University Community

INTRODUCTION

Today, cats, dogs, and birds, characterized as stray animals living in public spaces, exist outside the state's sphere of interest—except for measures taken during extraordinary periods—but are intertwined with society. With the transition to settled life, animals have reached an indispensable position in every aspect of human life. Dogs occupy an important position in social life, both because they have a special place in individuals' lives as pets and because they are one of the species frequently encountered in public spaces with their identity as stray animals. Archaeological findings indicate that the dog was the first domesticated animal species and has lived with human communities for approximately 15,000 years.

Today, dogs serve not only as domestic companions but also in many fields such as security, guidance, therapy, and search and rescue. However, especially in developing countries, dogs constitute a significant portion of stray animal populations and have become indispensable actors in public spaces in city life. In countries with high stray animal populations like Turkey, dogs have become an integral part of daily life. Therefore, attitudes toward dogs are critically important, not only for determining behaviors at the individual level but also for shaping social peace, animal welfare policies, and local government practices.

Particularly on university campuses, dogs have become a natural part of daily life for students and employees who are in contact with them, and this situation directly affects individuals' perceptions and attitudes towards dogs. While some individuals evaluate dogs as living beings that require love, compassion, and protection, others may perceive them as a threat or risk factor. University communities serve as an important social laboratory for observing these attitudes as they bring together individuals from different socio-cultural backgrounds. While students, representing the young population, are indicators of future social perceptions and behavioral patterns, academic staff are effective in shaping social views through their knowledge and awareness levels, and administrative staff contribute to the process with their practical experiences in campus life.

Research on dogs in Turkey has mostly focused on population control, welfare, or interactions of stray animals with humans; studies that reveal the attitudes of university communities towards dogs in a holistic manner are quite limited. This situation points to a significant gap in the literature. Investigating attitudes towards dogs is important not only for understanding behavioral patterns at the individual level but also for guiding social policies. For instance, the presence of stray animals on campuses can sometimes lead to security concerns and at other times to an increase in adoption and protection behaviors among students. This situation directly affects the policies of university administrations towards campus animals. Therefore, examining the attitudes of university communities towards dogs will fill a scientific gap and provide an opportunity to develop strategies that will contribute to regulatory practices for university life and social animal welfare policies.

In this context, the primary aim of this research is to examine the behaviors and attitudes of academic and administrative staff and university students towards dogs, to reveal similarities and differences between different groups, to determine positive or negative tendencies towards dogs, and to evaluate the potential reflections of these attitudes on social life, university administrations, and animal welfare policies. Thus, the findings to be obtained are expected to provide both a scientific basis for animal welfare studies and guidance for university administrations' regulatory practices regarding campus life.

GENERAL INFORMATION

2.1. The Place and Importance of Dogs in Human Society Throughout human history, dogs, as one of the earliest domesticated animals, have assumed a significant role in cultural, economic, and social life. Archaeological and genetic findings show that dogs were domesticated from wolves approximately 15,000 years ago and undertook functions such as hunting, protection, herding, and guarding in different societies. In the historical process, dogs have been evaluated not only as functional helpers but also as symbols of friendship and loyalty. Today, besides being considered pets that can establish emotional bonds with family members, dogs contribute to human life in many fields, such as police, guide, and therapy dogs. However, stray dogs appear as a noteworthy social phenomenon, particularly in urban life, triggering different attitudes and behaviors in individuals. In this context, university campuses are among the spaces where dogs experience intense interaction with humans. Therefore, the place of dogs in human society necessitates their examination not only as biological entities but also as a socio-cultural phenomenon.

History of domestication and cultural importance: The association of domestic animals with human life began with the domestication of the dog, continued with farm animals over time, and has expanded to species called "exotic animals," such as iguanas, snakes, and spiders, today. The concept of "pet" generally refers to animals whose feeding, care, and breeding are under human control. The process of dog domestication began approximately 20,000 to 40,000 years ago, during the period when humans subsisted on hunting and gathering. As the first domesticated animal species, the association of humans with dogs dates back 12-14 millennia according to archaeological sources, while genetic sources trace this development back to 100,000 years ago. Animals have existed in people's lives since the early times of civilization and have appeared many times as figures representing religion in addition to being domestic animals. With different breeds emerging since the day they were domesticated, dogs serve humans in many fields, such as search and rescue, herding, guard protection, guidance, hunting, and companionship. Animals have sometimes been friends we look after in our homes and gardens, and sometimes companions with whom we share our loneliness. Related to this, Ainsworth (1985) introduced the concept of "affectional bonds." This concept expresses not only the attachment felt towards the mother but also the attachment to pets.

The ancestors of the dog descended from species belonging to the Canidae family, a predatory mammal that appeared approximately 15 million years ago. Since the ancestors of modern dogs share a common ancestor with wolves (Canis lupus), important clues regarding the evolution of the dog also focus on the evolutionary history of wolves. The genus *Canis*, located in the evolutionary process of wolves, evolved approximately 2–3 million years ago in a way that would lead to the ancestors of modern dogs. The dog is one of the oldest and closest domestic animals in human history. From hunter-gatherer communities to modern societies, dogs have assumed both domestic and functional roles, becoming vitally important creatures for humans. The domestication of dogs not only led to the evolutionary transformation of a species but also caused an increase in the genetic diversity of dogs and the emergence of very different breeds.

Genetic diversity has been shaped in line with different environmental conditions and human needs; this situation has led to significant diversification in the physical characteristics and behaviors of dogs.

Sociological and psychological aspects of dog–human relationships: Throughout history, the relationship between animal and human health has shown similarities. Aristotle's examinations of human and animal bodies revealed parallels between anatomical structures and functions. Human-animal interactions have been at the center of not only cultural but also social and economic transformations in the historical process. Pets, especially dogs, constitute a significant part of these relationships. Among the main reasons for adopting pets, factors such as accepting animals as individuals in the family or adopting them as friends sharing the loneliness at home reveal people's social sharing needs in pet ownership. Especially after the 17th century, it is stated that animals were seen as a means of socialization, and the general attitude towards animals and nature evolved in a more positive direction compared to other ages.

As one of the oldest domesticated animals in human history, dogs have become an inseparable part of human life not only in domestic life but also in many fields such as security, therapy, guidance, and social support. It is known that the presence of animals plays an important role in reducing the feeling of loneliness and making the individual feel peaceful. Furthermore, in studies conducted with children in the home environment, specifically those accompanied by dogs, it is determined that these children have lower blood pressure levels compared to others. The first documented treatment regarding the use of animals' close relationship with humans to improve human health was applied by William Tuke in the late 18th century to patients with psychological disorders. In the 19th and 20th centuries, research on the animal-human relationship and the use of animals for therapeutic purposes showed an increasing trend. Today, these relationships show that human and animal health are interconnected within the framework of the "One Health" approach and should be addressed in an integrated manner with ecosystem health.

The place of dogs in urban life (stray dogs, adoption, shelters): The concept of "stray animal" is perceived differently in different societies. However, the term "stray animal," expressing this different perception, is used in daily life. Generally, the expression "stray animals" is a term used for homeless street animals. This expression brings to mind especially cats and dogs, which are encountered in greater numbers. Stray animals are animals that are condemned to live on the streets generally due to reasons such as people's temporary interests, lack of responsibility awareness, inability to allocate time or cash, health problems, and, unfortunately, natural disasters.

We define stray animals in three ways: 1) Free-ranging animals that do not have an owner but are fed by people and are not under control; 2) Animals without an owner; 3) Animals belonging to wildlife, abandoned to nature, and accustomed to humans can also be defined as stray animals, but their breeding for humans is not appropriate.

Kruk (2021) defined the concept of "stray animal" in his study as pets that are not at home or within the owner's boundaries and are out of the control of the owner or caregiver. Turkey accepted the European Convention for the Protection of Pet Animals in 2003. Humans beginning to dominate nature and transitioning to settled life led to the domestication of many wild animals and, subsequently, the emergence of stray animal status. In the historical process, these animals assumed functional roles within society. Cats contributed to the control of rodents, birds to pests, and dogs to garbage; additionally, dogs played a warning role in the security of neighborhoods. Cats, dogs, and birds, which are characterized as stray animals and live in the public sphere today, have lived intertwined with society, outside the state's sphere of

interest except for measures taken during extraordinary periods. While the number of people living in cities increased in the 1950s when there was intense migration from villages to cities in Turkey, the increase in the number of stray animals parallel to this trend came inevitable. Basically, the stray animal problem, formed through stray dogs, has been characterized and discussed as an urban problem in Turkey for a long time.

RESEARCH AND FINDINGS

Research Design: The aim of this research is to evaluate the attitudes and behaviors of academic and administrative staff and students in at universities toward dogs. The study a seeks to evaluate the degree of awareness concerning dogs, experiences of pet ownership, frequency of interactions with dogs, and attitudes towards the environments in which dogs reside this descriptive study was intended to be carried out using quantitative data collection techniques via face-to-face and online survey methods.

Universe and Sample: The universe of this research consists of academic and administrative staff working at universities in Turkey and students studying at the undergraduate level. The sample consists of volunteer participants working and studying at eight universities located in different geographical regions, primarily Erciyes University.

Institutional Permissions: Within the scope of the study, official institutional permission applications were made to a total of 15 universities for the survey implementation. As a result of these applications, positive feedback was received from the 8 universities listed below, and survey implementations were carried out only in these universities:

-
- Erciyes University (Central Anatolia)
- Burdur Mehmet Akif Ersoy University (Mediterranean)
- Afyon Kocatepe University (Aegean)
- Aydın Adnan Menderes University (Aegean)
- Hatay Mustafa Kemal University (East/Southeast)
- Kafkas University (East/Southeast)
- Bursa Uludağ University (Marmara)
- Selçuk University (Central Anatolia)

Academic and administrative staff and undergraduates working/studying at these universities formed the study sample. The sample selection acted on a voluntary basis. Individuals participating in the study were informed about the purpose and scope of the survey and were included in the process after obtaining their consent.

Data Collection Tool: Research data were collected through face-to-face and online survey methods. In both methods, participant confidentiality was protected, and participation was ensured on a voluntary basis.

Face-to-Face Surveys: Face-to-face survey applications were carried out for academic and administrative staff and undergraduates working on university campuses. Surveys were administered by researchers assigned to determined campus areas using the one-on-one interview method. Participants were informed about the purpose and scope of the research and the conditions of participation based on voluntariness, and the data collection process was initiated after their approval was obtained.

Online Surveys: The online survey method was used to obtain data from academic and administrative staff and students working at universities outside the institution. The survey form was prepared via Google Forms and delivered to participants via the official e-mail addresses of the relevant institutions. Explanations regarding the purpose of the study, confidentiality principles, and voluntariness were included at the beginning of the survey link.

The applied survey form consists of six sections:

1. Demographic Information: Includes questions regarding participants' socio-demographic characteristics such as age, gender, occupation, educational status, and monthly household income.

2. Attitude Towards Dogs: Consists of statements aimed at evaluating participants' attitudes towards stray dogs and keeping dogs at home.

3. Adoption and Care: Includes questions regarding participants' dog ownership status, reasons for adoption, gender of owned dogs, and health status.

4. Health: Consists of statements aimed at measuring dogs' health status, vaccination frequency, and feeding habits.

5. Training and Human–Dog Relationships: Contains questions regarding dogs' training processes, forms of social interaction, and general behavioral characteristics.

6. Dogs' Reaction to Environmental Stimuli and Social Interaction Needs: Consists of statements aimed at evaluating dogs' reactions to environmental factors, social interaction requirements, and coping with stress.

Data Collection Process: Survey applications were conducted between December 2024 and January 2025. The data collection process was carried out for academic and administrative staff and undergraduates working at universities where official permission was obtained within the scope of the research. Survey forms were administered by the researcher both in printed media and online via Google Forms. Face-to-face surveys were conducted by the researcher using the one-on-one interview method on permitted campuses; online forms were delivered to participants via the official e-mail addresses of the relevant institutions. All participants were informed before participating in the research, and voluntary participation consent was obtained. Surveys were administered anonymously, and no personal or identity information was collected. Scientific ethical principles were fully observed throughout the research process, and an "Ethics Committee Exemption Certificate" was obtained from the Erciyes University Institute of Social Sciences (Document Date: April 30, 2024, Application No: 173).

Data Analysis: After defining categorical and continuous variables, the obtained data were evaluated in the JMP Pro 16.01 statistical software package and the R 4.5.2 platform. Analyses were performed in terms of distributions, differences, and correlations. Relationships between categorical variables were evaluated with the Pearson Chi-Square test and Cramér’s V effect size; differences of continuous variables on categorical attitude structures were tested with the nonparametric Kruskal–Wallis test. Relationships between variables were examined with Spearman correlation.

FINDINGS

In this section, findings regarding the attitudes, behaviors, and adoption tendencies of individuals in the university community towards dogs are presented in percentage distributions. The data are based on the responses of 1,033 individuals participating in the research. The obtained results were evaluated using descriptive statistics and chi-square analyses. Within the scope of the findings, participants' demographic characteristics, dog ownership status, attitudes towards stray dogs, and evaluations regarding dogs' care, welfare, and behavioral requirements were examined in detail.

Demographic Findings: Findings regarding participants' demographic characteristics (gender, age, occupation, and income) are detailed below:

Gender: Of the total 1,033 individuals participating in the research, 55.57% (n=574) are female and 44.43% (n=459) are male. This distribution shows that female participants are represented at a slightly higher rate than males in the sample. This difference in gender distribution suggests that female participation is higher in the overall study, thus forming a significant basis for examining gender differences in some variables regarding dog attitudes and behaviors.

Age Range: When participants' age ranges are examined, it is seen that the 18–25 age group provided the highest participation by a clear margin (84.80%; n=876). This is followed by the 26–33 age range at 6.97% (n=72) and the 34–41 age range at 4.16% (n=43). The rate of participants in the 42–49 age range was determined as 2.32% (n=24), and those aged 50 and over as 1.74% (n=18). This finding indicates that the study sample consists largely of young individuals, especially university students, and therefore the results represent the attitudes of the young adult population.

Occupation: When the occupational distribution of participants is examined, students formed the largest group by a clear margin (92.16%; n=952). The academic staff rate was determined as 4.45% (n=46), and the administrative staff rate as 3.39% (n=35). This result confirms that the target group of the study is university students; however, it shows that there is also significant participation from academic and administrative staff. This diversity provides valuable data for comparing the perceptions of individuals in different roles within the university community towards dogs.

Monthly Income (TL/Month): When participants' monthly household income levels are examined, those with an income of 45,000 TL and above formed the highest group with 33.01% (n=341). This was followed by individuals in the income group of 15,000 TL and below at a rate of 27.40% (n=283). Distributions were observed in the middle-income groups as 15,001–25,000 TL (16.07%; n=166), 25,001–35,000 TL (12.39%; n=128), and 35,001–45,000 TL (11.13%; n=115). Findings show that a significant portion of participants are in the middle-upper income group, but the low-income group is also strongly represented in the study.

Findings on Pet Ownership and Attitudes: Presence of Pets at Home: Approximately half of the participants (49.27%; n=509) stated that they currently keep a pet at home. Additionally, 19.65% (n=203) stated that they very much want to adopt a pet in the future, while 30.11% (n=311) stated that they do not have any pets. A rate of 0.97% (n=10) of participants stated that they do not consider adopting a pet. This result reveals that the potential for pet ownership is quite high and there is a general acceptance tendency towards pets in society.

Monthly Expenditure for Pet: When the average monthly expenditure levels of participants with pets (n=326) are examined, the highest rate is in the 2,001–5,000 TL range with 45.71% (n=149). This is followed by the range of 2,000 TL and below with a rate of 41.10% (n=134). Those spending in the 5,001–10,000 TL range were 9.82% (n=32), those in the 10,001–15,000 TL range were 2.45% (n=8), and those spending over 15,000 TL took place at a rate of 0.92%

(n=3). These findings show that most pet owners spend at a moderate level, and those making high expenditures constitute a very limited group.

Attitude Towards Stray Dogs: Participants' attitudes towards stray dogs are quite varied. More than half of the participants (51.21%; n=529) chose the statement "I love them, and I am not afraid." The rate of those saying "I love them, but I am afraid" is 23.43% (n=242). Among more negative attitudes, responses included "They should be collected" at 12.58% (n=130), "They should be put to sleep" at 7.26% (n=75), and "I have no idea" at 2.71% (n=28). This finding shows that a love-based but cautious approach towards stray dogs prevails in society in general.

Thought of Keeping a Dog at Home: When participants' views on keeping a dog are examined, 46.95% (n=485) gave the response "I would like to feed one provided it is in the garden (outside the house)." While 25.46% (n=263) said, "I would like to keep one at home," 10.65% (n=110) stated that they currently keep a dog. The rates of those expressing negative views are 7.16% (n=74) "I do not want to" and 4.55% (n=47) "I definitely do not want to." These results show that although there is generally a positive approach to the idea of keeping a dog in society, the vast majority tend to keep the dog outside the house.

Findings Regarding Dog Ownership and Care Processes: Dog Ownership Status: 68.25% (n=705) of the participants stated that they had never owned a dog, 18.59% (n=192) that they currently own a dog, and 13.17% (n=136) that they owned a dog in the past. This distribution shows that dog ownership is widespread in a limited segment of society, but individuals who have experienced ownership in the past are present in a substantial ratio.

Knowledge and Opportunity Regarding Dog Adoption and Care: Of the 412 participants responding to this question, 60.68% (n=250) considered themselves sufficient regarding dog adoption and care. 28.16% (n=116) stated they were not sufficient, while 11.17% (n=46) gave the response "I am eager; we can cope with this situation together with my dog." This finding reveals that although the desire to adopt a dog is high, a significant portion of the participants feel a lack of knowledge or resources.

Reasons for Adoption: When participants' reasons for dog adoption are examined, the most frequently stated reason was friendship or companionship (47.24%; n=257). This is followed by protection/security purposes (24.45%; n=133) and hobby/activity (17.83%; n=97). Moving away from people (7.17%; n=39) and treatment or guidance purposes (3.31%; n=18) were stated at lower rates. This result shows that dogs are primarily considered social and emotional companions, and functional reasons (such as protection or therapy) remain in the background.

Effective Factors in Adoption Decisions: When factors affecting the dog adoption decision were evaluated, the vast majority of participants (72.93%; n = 256) gave the response, I decided without being influenced by anyone." Parents having a dog (20.51%; n=72) ranked second, while friend influence (3.42%; n=12), child's request (1.99%; n=7), and media influence (1.14%; n=4) were seen at quite low rates. This finding shows that the adoption decision is mostly an individual preference, and social circle or media influence remains limited.

Place of Adoption: When examining where participants adopted their dogs, the highest rate was the "gifted" option with 36.31% (n=118). This was followed by adoption from a breeder (31.08%; n=101) and adoption from a shelter (24.00%; n=78). Adoption rates from pet shops (5.54%; n=18) and veterinary clinics (3.08%; n=10) are at low levels. Findings show that shelter-sourced adoption exhibits a positive trend, but gift and breeder-sourced adoption are still widespread.

Adoption Cost: When the status of paying any fee during adoption was examined, 68.03% (n=217) of the participants gave the response, “No, I adopted completely free of charge." In contrast, 31.97% (n=102) stated that they paid a fee, such as for food, vaccine, or service, for

the dog they adopted. This result shows that adoption largely takes place through a voluntary process far from the expectation of financial gain.

Dog's Pedigree Status: When the pedigree statuses of participants' dogs are examined, 69.26% (n=223) stated that their dog did not have a pedigree document, while 30.75% (n=99) stated that a pedigree document was present. These rates show that registered purebred dogs are found in a limited ratio in our country, and adoptions mostly consist of undocumented dogs.

Pedigree Importance Level: When the levels of importance participants attach to pedigree or being purebred were evaluated, 80.30% (n=269) selected the response "never important." In contrast, only 19.70% (n=66) said "yes, important." This finding shows that the majority of participants evaluate the dog on the basis of emotional bonding rather than as a status indicator or breed-based preference element.

Place of Owned Dogs in Society: Looking at participants' views on the place of owned dogs in society, 67.38% (n=696) said, "They provide positive contributions to society." While 20.62% (n=213) responded "they have neither positive nor negative effects," 8.81% (n=91) said "I am undecided," and 3.20% (n=33) said "there are negative effects." This result shows that owned dogs are generally perceived as a positive element in society.

Place of Stray Dogs in Society: When the social perception regarding stray dogs was evaluated, 46.08% (n=476) of the participants said, "They have negative effects for society." In contrast, 18.97% (n=196) staff participants stated that "stray dogs provide positive contributions to society," while 18.10% (n=187) were "undecided," and 16.84% (n=174) believed that "stray dog save no effect." These findings reveal that stray dogs are perceived more as a risk element within society.

Dog Breed: When the distribution regarding dog breeds is examined, it is seen that Kangal mix dogs are at the highest rate by a clear margin (72.45%; n=894). This is followed by Kangal (6.30%; n=72), Terrier (2.67%; n=33), and Akbaş (2.67%; n=33). Other breeds (Rottweiler, Golden Retriever, Labrador, Cocker Spaniel, etc.) were represented at much lower rates. This finding shows that native breeds—especially Kangal and its mixes—are dominant in regional adoptions.

Dog's Age: When the age distribution of dogs is examined, dogs in the 1–5 age range are at the highest rate by a clear margin (50.78%; n=163). The rate of dogs under one year old was determined as 13.71% (n=44), 6–10 years old as 16.20% (n=52), over 10 years old as 9.66% (n=31), and those who do not know the age as 9.66% (n=31). This finding shows that most owned dogs are in the young adult age group.

Dog's Gender: According to the declarations of dog owners, 63.45% (n=184) of the dogs they own are male; 36.55% (n=106) are female. This distribution shows that the rate of adopting male dogs is higher.

Neutering Status: When the neutering status of dogs is examined, 7227.65% (n=81) of owners neutered their dog, while 72.36% (n=212) did not This result shows that neutering rates are quite low and points to the necessity of awareness studies on the subject.

Place Where Neutering Was Performed: 50% (n=52) of the participants (n=104) who had their dog neutered stated that the procedure was done at the veterinary clinic they regularly visit. 28.85% (n=n = 30) marked the option "I have no information about the subject"; 8.65% (n = 9) marked "at a municipal facility," 6.73% (n = 7) marked "at another recommended clinic," and 5.77% (n = 6) marked at a university hospital." Findings show that neutering procedures are mostly carried out in private veterinary clinics.

Status of Having Offspring Before Neutering: 41.77% (n=66) of the 158 participants who had their dog neutered gave the response "We neutered before giving birth." 39.24% (n=62) used the expression "I have no information about the subject," 12.66% (n=20) "gave birth once," 5.06% (n=8) "gave birth twice," and 1.27% (n=2) "gave birth three times." This result shows that most dog owners tend to neuter before birth.

Reasons for Not Neutering: According to the statements of 192 participants who did not neuter their dog, the most common reason, with a rate of 35.05% (n=102), was "I might consider neutering; I haven't had a problem yet." This is followed by "I don't want it to feel pain" (17.87%; n=52) and "empathy/emotional reasons" (17.87%; n=52). Also, 12.03% (n=35) gave the response "I think it is a practice against nature," 7.56% (n=22) "an unhealthy practice," and 5.15% (n=15) "religious or conscientious reasons." These findings reveal that the reasons for not neutering are mostly based on emotional and moral foundations.

Dog's Health Status: When responses regarding the health status of dogs are examined, the highest rate belongs to the response "has no health problems" with 45.73% (n=193). 31.52% (n=133) stated "I have it vaccinated regularly," 5.92% (n=25) "have a chronic disease," 4.03% (n=17) "I have it vaccinated irregularly," and 2.61% (n=11) "unvaccinated." 4.27% (n=18) said, "I am not knowledgeable." These findings show that the vast majority of owned dogs are subjected to regular health checks.

Fear of Dogs Before Adoption: When the fear status of dog owners before adopting a dog was examined, 89.35% (n = 260) gave the response, "No I had no fear." 8.59% (n = 25) said, "I did; I overcame the fear when I adopted," and 2.06% (n = 6) said, "I did, but I still fear after adoption." This result shows that pre-adoption fears largely disappear with experience.

Order of Ownership: When the ownership order of the dogs owned by the participants was evaluated, 64.51% (n = 189) gave the response, "I am the first owner." 21.84% (n=64) marked the options. "I am the second owner." 11.26% (n=33) "I don't know," and 2.39% (n=7) "I am the third owner." This result shows that a large portion of the dogs were adopted by their first owner.

Age at Adoption: When the age at which the dog was adopted is examined, 46.23% (n=135) of the participants stated that they adopted in the "suckling period–3 months" range. 26.71% (n=78) said "4–6 months," 12.33% (n=36) "I adopted without knowing the age," 8.22% (n=24) "6–12 months," 4.11% (n=12) "1 year old," and 2.40% (n=7) "2 years old." This finding reveals that dog adoptions mostly take place in the puppy period.

Number of Daily Food Meals: When the number of daily food meals given to dogs is examined, 49.48% (n=143) of the owners stated that they feed their dog twice a day, and 22.15% (n=64) stated that they feed "ad libitum" (free access). 20.42% (n=59) marked the option "three meals," and 7.96% (n=23) "one meal." Findings show that the vast majority of dogs are fed regularly at two meals.

Number of Daily Water Meals: Findings regarding the amount of water given to dogs show that the vast majority of owners, 88.62% (n=257), provide their dogs with "ad libitum" (continuous access) opportunity. Apart from this, 5.17% (n=15) reported giving water three times a day, 4.83% (n=14) twice a day, and 1.38% (n=4) once a day. This result shows that most dog owners exhibit an ideal approach regarding water supply.

Findings on Behavior, Training, and Welfare: Dog's Training Status: Examining participants' responses about their dogs' training levels, we found that 57.75% (n=164) said their dog was "trained by the owner." 28.52% (n=81) of participants responded that their dog "received no training," 10.56% (n=30) indicated their dog was "trained by an amateur trainer," and 3.17%

(n=9) reported their dog was "trained by a professional trainer." Findings show that an owner-based approach is more common in dog training than professional support.

Type of Collar Used: When the types of collars used by dog owners are examined, 52.65% (n=149) stated that they use a "neck collar." This was followed by the options "harness/chest collar" at 29.33% (n=83), "I do not use a collar" at 15.19% (n=43), and "choke/training collar" at 2.83% (n=8). This finding shows that a large portion of owners prefer standard collar models, prioritizing the dog's comfort.

Attitude Towards Other Family Members: When dogs' attitudes towards other individuals in the family are examined, 60.65% (n=168) of the participants stated that their dog behaves "very well" and 31.05% (n=86) "well." Responses of "unresponsive" were 3.97% (n=11), "bad" 2.89% (n=8), and "very bad" 1.44% (n=4). This finding reveals that the intra-family harmony of owned dogs is high.

Attitude Towards Children at Home: When dogs' attitudes towards children are examined in households with children under 14 years of age, 62.08% (n=149) were evaluated as "very good" and 27.08% (n=65) as "good." "Unresponsive" was stated as 5.83% (n=14), "bad" as 3.33% (n=8), and "very bad" as 1.67% (n=4). Findings show that dogs generally exhibit a positive and compatible attitude towards children.

Attitude Towards Guests: When dogs' attitudes towards guests coming to the house are examined, responses were 35.64% (n=98) "good," 35.27% (n=97) "very good," 16.73% (n=46) "bad," 8.00% (n=22) "unresponsive," and 4.36% (n=12) "very bad." This distribution shows that a large portion of dogs are socially accustomed to accepting guests, but a certain group may show protective or shy behaviors.

Attitude Towards People Outside: When the attitudes of participants' dogs towards people they encounter outside are examined, they were reported as "good" by 36.46% (n=101), "very good" by 23.47% (n=65), "unresponsive" by 21.30% (n=59), "bad" by 12.99% (n=36), and "very bad" by 5.78% (n=16). This result reveals that most dogs can establish positive interactions with people in the external environment, but some may show shy or protective reactions.

Attitude Towards Other Dogs Outside: When dogs' behaviors towards other dogs outside were examined, they were evaluated as "good" by 40.22% (n=111) and "very good" by 17.39% (n=48). In contrast, responses of "bad" (25.00%; n=69), "unresponsive" (11.23%; n=31), and "very terrible(6.16%; n=17) were received. This finding shows that while social tolerance among dogs is generally positive, aggressive or shy behaviors can also be seen at a certain rate.

Ability to Stay Alone at Home: When dogs' skills to stay alone at home are examined, 55.20% (n=154) gave the response "can stay alone for a full day." 20.43% (n = 57) said "up to half a day," 16.13% (n = 45) said "up to 6 hours," and 8.24% (n = 23) said "no, I can't stay alone." Findings show that most owned dogs adapt to being alone.

Status of Damaging Household Goods and Clothes: When dogs' behaviors towards household goods and clothes are evaluated, 48.72% (n=133) marked the option "has no habit of damaging." Responses of "sometimes, especially when bored or left alone" were 23.81% (n=65), "rarely but plays with toys" 20.51% (n=56), and "frequently causes damage" 6.96% (n=19). This result shows that destructive behaviors are at a low level in most dogs but may increase in situations such as loneliness or boredom.

Level of Meeting Dog's Daily Emotional Needs: When the level of meeting emotional needs such as play, attention, and walking is examined, 53.96% (n=150) of the participants responded "sufficiently met," 37.05% (n=103) "partially met," 6.84% (n=19) "not sure," and 2.16% (n=6)

"not met." This result shows that a large portion of dog owners pay attention to their animals' emotional welfare.

Housing Type: When the type of housing where dogs live is examined, 66.08% (n=187) marked the option "detached house with garden," 28.27% (n=80) "apartment," and 5.65% (n=16) "detached house with common area." This finding shows that owned dogs mostly live in houses with access to open space and points to a positive condition in terms of dog welfare.

Number of Daily Walks: Data regarding the frequency of taking dogs outside show that 31.64% (n=87) gave responses of "at irregular intervals during the week," 30.18% (n=83) "twice a day," 21.46% (n=59) "three times or more," and 16.73% (n=46) "once a day." This distribution reveals that most dogs engage in regular daily exercise, but irregularity is observed in some.

Average Duration of Each Walk: Evaluated in terms of the duration of each walk, 59.56% (n=162) of dog owners stated that they walk their dog between half an hour and one hour. 22.06% (n=60) responded "less than half an hour" and 18.38% (n=50) "longer than two hours." This finding shows that most owned dogs access sufficient physical activity daily.

Walking Area Preferences: When the areas where participants walk their dogs most frequently are evaluated, the highest rate was "parks and green areas" with 27.59% (n=168). This was followed by "surroundings of the house" (19.70%; n=120), "rural areas and fields" (17.41%; n=106), "forested areas" (12.15%; n=74), "city streets" (11.82%; n=72), and "dog parks" (5.42%; n=33). This distribution shows that dog owners tend to prefer natural areas.

Quality of Social Interactions: When dogs' forms of social interaction are examined, 41.50% (n=122) gave responses of "interaction with family members and friends," 23.13% (n=68) "encountering people and other animals on walks," 20.07% (n=59) "regular play and socialization with other dogs," 7.14% (n=21) "mostly at home," and 7.14% (n=21) "very little social interaction." This result shows that dogs' social needs are mostly met through human-centered interactions.

Reaction to Environmental Stimuli: When dogs' reactions to environmental stimuli are evaluated, 59.06% (n=163) were reported as "gives very positive reactions," 23.55% (n=65) "shows interest but is shy," 11.59% (n=32) "shows fear or aggressiveness," and 5.80% (n=16) "generally uninterested or unresponsive." Findings reveal that dogs are generally curious and react positively to the environment.

Reaction to Learning and Training Processes: When dogs' learning speeds and reactions to training processes are examined, 40.28% (n=114) were reported as "interested but learning speed is average," 39.93% (n=113) ""learns very quickly and eager for training," 10.25% (n=29) "struggles to learn, requires extra encouragement," and 9.54% (n=27) "uninterested or resistant." This finding shows that a large portion of owned dogs are open to learning and motivated.

Stress Coping Level: When dogs' ways of coping with stressful situations are examined, 48.73% (n=134) responded "takes some time but calms down," 39.27% (n=108) "calms down easily and quickly," 6.18% (n=17) "becomes uncontrollable, aggressive, or fearful," and 5.82% (n=16) "remains stressful for a long time." Findings show that the vast majority of dogs possess the skill to cope with stress.

View on Keeping Dogs at Home: Of the 305 participants responding to this question, 48.85% (n=149) gave responses of "I am in favor of feeding only in houses with gardens," and 44.59% (n=136) said, "I am pleased to keep at home; I find it positive." 4.26% (n=13) expressed the view, "I cannot bear the responsibility of keeping a dog." 1.64% (n=5) said, "I definitely do not find it appropriate," and 0.66% (n=2) said, "I am against keeping dogs." This distribution

reveals that a positive attitude generally prevails towards dog ownership, but living space conditions are a determining factor.

Belief Level in Cognitive Features in Dogs: When participants' beliefs regarding whether dogs possess cognitive features (intelligence, emotion, reasoning, curiosity, etc.) are examined, 80.00% (n = 244) gave the response, "Yes, I believe they exist." 16.07% (n=49) used the expression "I think some features exist partially." 2.62% (n=8) said, "No, I think these features do not exist," and 1.31% (n=4) said, "I am not sure." This result reveals that the vast majority of participants view dogs as living beings with cognitive capacity.

Level of Caring About Dog Psychology: When the level of importance dog owners attach to dog psychology is evaluated, 46.36% (n=140) gave responses of "very high," 35.76% (n=108) "high," 17.22% (n=52) "medium," and 0.66% (n=2) "very low." This finding proves that a significant portion of dog owners show high sensitivity to the dog's mental and emotional state.

Knowledge Level About Dogs' Psychological Welfare and Behaviors: When participants' knowledge levels regarding dogs' psychological welfare and behaviors were examined, they were reported as "medium level" by 36.96% (n=112), "high" by 35.97% (n=109), "very high" by 21.12% (n=64), "low" by 4.62% (n=14), and "very low" by 1.32% (n=4). This result shows that participants' awareness regarding the subject is generally strong.

Regular Veterinary Checks: When the status of taking dogs for regular veterinary checks is examined, 55.44% (n=158) gave responses of "yes, regularly," 36.84% (n=105) "only, when necessary," and 7.72% (n=22) "no, I do not." Findings show that a large portion of owned dogs are subjected to regular veterinary control.

Types of Food the Dog is Fed: When the types of food dogs are fed were evaluated with multiple choice, the most frequently reported type was high-quality dry food (33.10%; n=139). This was followed by homemade meals (29.76%; n=125), economic dry food (17.62%; n=74), raw feeding—BARF type (10.95%; n=46), and canned food (8.57%; n=36). These results show that dog owners attach importance to balanced nutrition and supplement ready-made foods with traditional foods.

Supplementary Foods Given Besides Kibble: When supplementary foods given to dogs besides kibble are evaluated, responses were received as "cooked meat or fish" (30.27%; n=181), "special dog treats" (19.06%; n=114), "butcher's by-products" (14.38%; n=86), "fresh vegetables and fruits" (12.21%; n=73), "uncooked bones" (11.20%; n=67), "grains or rice" (9.36%; n=56), and "I give no supplementary food" (3.51%; n=21). This distribution shows that most owners supplement dog nutrition with various natural foods.

Preference for Leaving the Dog on Vacation: When dog owners' practices regarding their dogs during vacation periods are examined, 39.93% (n=107) gave responses of "I leave it to my friend." 26.49% (n=71) "I take it with me," 24.25% (n=65) "I cannot leave it to anyone; I do not go on vacation." 4.85% (n=13) "I leave it to the veterinary clinic," and 4.48% (n=12) "I leave it to a boarding facility." Findings reveal that owners tend to leave their dogs with a trusted circle or take them along with them.

Effect of Dog Adoption on Social Circle: When the effects of dog adoption on social circle relationships are examined, 35.21% (n=94) gave the response "no change occurred; they remained neutral." 31.46% (n=84) stated "their social circle was "affected very positively, with increased interest and support," 28.46% (n=76) reported it was "affected positively but with some reservations," 4.12% (n=11) indicated it was "affected negatively, with increased anxiety and criticisms," and 0.75% (n=2) said it was affected very negatively." This result shows that dog adoption generally finds a positive response in the social circle.

Effect of Dog Adoption on Family Budget: When the economic effects of dog adoption are evaluated, 45.76% (n=124) gave the response "no significant change occurred. "This is followed by the options 'did not affect at all, I can cover the costs easily' (23.62%; n=64), 'affected negatively to some extent, small budget changes occurred' (21.03%; n=57), 'affected negatively in a serious manner' (5.53%; n=15), and 'affected positively, made the budget more planned' (4.06%; n=11). Findings show that dog adoption has an effect at a manageable level economically.

Regret Felt from Dog Adoption: Findings regarding the level of regret felt from the dog adoption decision show that 48.54% (n=133) of the participants gave the response "no, I am very happy; my life changed positively." 22.99% (n=63) gave responses of "I encountered partial difficulties, but generally I am happy." 22.99% (n=63) said, "I am not regretful; I find my decision positive," and 5.47% (n=15) said, "Yes, I am regretful." This result shows that dog adoption generally contributes positively to individuals' life satisfaction.

Comparative and Advanced Statistical Findings:

Findings Related to Gender: A statistically significant and strong relationship was found between gender and attitudes towards stray dogs ($\chi^2 = 186.61$, $p < 0.001$, Cramér's $V = 0.425$). While 58% of women gave the response, "I love them, and I am not afraid," this rate remained at 42.7% for men. 29.3% of men chose the statement, I support them being collected." This result indicates that women exhibit a more empathetic and protective attitude towards stray dogs. Additionally, a strong relationship was determined between gender and the thought of keeping a dog at home ($\chi^2 = 51.36$, $p < 0.001$, Cramér's $V = 0.410$), indicating that acceptance levels of women and men differ significantly.

Findings Related to Age Groups: A significant difference was determined among age groups in attitude towards stray dogs ($\chi^2 = 56.12$; $p < 0.001$; Cramér's $V = 0.27$). 59.4% of individuals in the 18–25 age group marked the option "I love them and I am not afraid," whereas this rate fell to 41.8% in the 36–45 age group. The response "I am afraid, and I stay away" was observed at a rate of 22.5% in those aged 46 and over. This finding shows that the young age group exhibits a more positive and sensitive attitude towards stray dogs.

Factors Determining Dog Ownership (Logistic Regression): The logistic regression model developed to examine determinants affecting dog ownership showed that the presence of pets at home (OR=0.17; $p<0.001$), attitude regarding the social role of stray dogs (OR=2.59; $p=0.001$), and desire to keep a dog at home (OR=0.09; $p<0.001$) form significant and strong effects on ownership. Ownership significantly decreases in those without pet experience at home.

Spearman Correlation Analyses: Knowledge—Psychology: "Participants with higher knowledge about dogs' psychological welfare and behaviors also report a higher level of caring about dog psychology" ($r = 0.24$). This relationship is a direct and consistent finding.

Age–Income: A limited increase is observed in income levels as participants' ages increase ($r = 0.21$).

In general, relationships between the examined demographic (age, income) and ownership variables and psychological welfare and attitude indicators are at a weak level.

Analyses in Dog Owners Subgroup: In analyses performed in the dog owner's subgroup, the only significant result is the difference between the dog's training level and the dog owner's age ($p < 0.001$). While young owners (18–35 years) reported their dogs more in the "received training" category, the training level decreases as age progresses. This finding shows that dog training is an age-sensitive behavioral investment.

DISCUSSION & CONCLUSION

Discussion

The findings of this research show that the attitudes and behaviors of academic and administrative staff and students in universities towards dogs are generally positive but carry significant differences in terms of different variables. Data obtained from 1,033 individuals participating in the research revealed that empathy and awareness regarding dogs are high in the educated segment of society, yet knowledge level is not always reflected in practical behaviors.

Attitudes and Behaviors According to Gender Variable: Findings indicate that gender creates a significant difference in attitudes towards dogs. While female participants preferred the statement "I love them and I am not afraid" at a rate of 58%, this rate remained at 42.7% in males. In contrast, it was determined that male participants showed a greater tendency towards negative judgments such as "should be collected" and "should be put to sleep." This result shows that women generally exhibit a more empathetic, emotional, and protective apattitude towardogs. Studies conducted by Yılmaz, Özcan, and Şen (2021) and Herzog (2007) in the literature also emphasize that women's compassion level towards animals is higher than men's, based on biological and social learning foundations. In societies like Turkey, where emotional care is culturally attributed more to women, it is seen that these tendencies are also reflected in relationships established with animals.

Attitudes and Behaviors According to Age Range: According to research findings, the vast majority of participants (84.80%) are in the 18–25 age range. Young adults used the expressions "I love them" and "I am not afraid" more frequently, showing a high potential for establishing an emotional bond towards dogs. It was observed that positive attitudes towards dogs decreased as age increased, and the rate of responses such as "should be collected" or "I am afraid" rose in middle-age groups. Evaluated in terms of behavioral sciences, the high levels of animal love in young participants can be explained by social learning, emotional development, and social modeling in the campus environment. The tendency of individuals in advanced age groups to maintain physical distance from dogs generally stems from life experiences or negative observations.

Attitudes and Behaviors According to Occupation Variable: Significant differences were observed in dog attitudes according to the occupation variable. While academic staff exhibited a more conscious approach with high emphasis on ethical responsibility regarding "animal welfare" and "owned–stray dog distinction," students approached more on the basis of emotional bonding and desire for adoption. It was determined that administrative staff had a more pragmatic and distant tendency. This situation is compatible with the study of Erdoğan and Yıldız (2020), showing that academic education develops not only cognitive knowledge but also ethical sensitivity.

Attitudes and Behaviors According to Income Level: It was determined that individuals in the high-income group had higher awareness regarding dog ownership, dog care, and dog welfare, whereas those in the low-income group had strong emotional orientations despite low adoption rates. While professional care and welfare-oriented attitudes are seen in high-income individuals, emotional closeness and desire for protection stand out in middle- and low-income groups. Although income level affects behaviors towards dogs quantitatively, it is not the sole determinant qualitatively in terms of emotional attachment.

Status of Pets Present at Home: It was determined that the attitudes of individuals with pets at home towards dogs were significantly more positive. While pet owners selected the statement "I love them and I am not afraid" at a higher rate, statements of "should be collected" and "I am

afraid" increased in individuals without pets. This situation shows parallelism with the study of Ergin, Pekşen, and Diker (2011), showing that pet ownership increases empathy levels and reduces fear/prejudice rates.

Attitudes Towards Stray Dogs: It was seen that a love-based but cautious approach towards stray dogs prevails in society. While more than half of the participants expressed positive views, there is also a significant segment carrying security concerns. This situation reveals that the social attitude towards stray dogs possesses a dual structure (love and fear).

Knowledge-Action Gap: One of the most striking discussion points of the study is the gap between knowledge and practice. Although the vast majority of participants stated that they care about dog care and welfare, the low rates of neutering (27.65%) and the training level being far from professionalism (mostly training by the owner) show that the level of consciousness does not always transform into action.

Conclusion

This research addressed the attitudes of academic and administrative staff and students in universities towards dogs with a holistic approach. Findings show that participants generally exhibit an empathetic, sensitive, and welfare-oriented approach towards dogs.

Key Results:

Gender Effect: Female participants exhibit a more protective and empathetic attitude compared to males.

Age Effect: Love for animals and positive attitude are stronger in young individuals (18-25 years); cautious approach increases as age progresses.

Income and Profession Effect: While a knowledge-based and professional approach is dominant in high-income and academic staff groups, emotional attachment is at the forefront in students and low-income groups.

Ownership Effect: Pet ownership is one of the strongest determinants of positive attitudes towards dogs.

Knowledge-Action Inconsistency: It was determined that even individuals with high levels of knowledge show behavioral inconsistencies in practice (e.g., regarding neutering) ("knowledge-action gap").

Recommendations:

Education and Awareness: Seminars and elective courses on "Animal Welfare and Behavioral Psychology" should be organized in universities, and all staff and students should be included in these processes.

Campus Animal Policies: University administrations should turn feeding, shelter, and health services for stray animals into institutional policies and carry out these practices in cooperation with volunteer student communities.

Neutering Consciousness: The importance of neutering for balancing the owned and stray dog population should be emphasized; informational activities should be carried out in cooperation with veterinary faculties.

Social Empathy: Content that will reduce false perceptions regarding dogs and highlight empathy and scientific knowledge should be produced in mass media tools.

Future Research: It is suggested that future studies examine individuals' emotional bonds and ethical approaches in more detail with qualitative methods (in-depth interviews, etc.).

In conclusion, universities taking an active role in education and social responsibility areas that reinforce this consciousness will be the key to reaching a sustainable social structure in terms of dog welfare.

REFERENCES

Ainsworth (1985) Koç, B., Altunçul, H., & Filoğlu, G. (2014). Türkiye'de veteriner hekimlerin, veteriner fakültesi öğrencilerinin ve kanun uygulayıcıların hayvan haklarına yönelik tutumları üzerine bir araştırma. İstanbul Üniversitesi Veteriner Fakültesi Dergisi, 40(2), 147-154.

Erdoğan, A., & Yıldız, S. (2020). Akademisyenlerin hayvan haklarına yönelik tutumları: Bilimsel bilgi ve etik çerçeve. Anadolu Üniversitesi Sosyal Bilimler Dergisi, 20(3), 355-372.

Ergin, İ., Pekşen, Y., & Diker, A. (2011). Türkiye'de toplumun hayvan sevgisi ve hayvanlara bakış açısı üzerine bir araştırma. Kafkas Üniversitesi Veteriner Fakültesi Dergisi, 17(5), 871–878. https://vetdergikafkas.org/pdf.php?id=1304

Herzog, H. (2011). The impact of pets on human health and psychological well-being: Fact, fiction, or hypothesis? Current Directions in Psychological Science, 20(4), 236–239. https://doi.org/10.1177/0963721411415220

Kruk, E. (2021). Companion animal neglect and homelessness: Conceptual definitions and implications. Journal of Animal Ethics, 11(1), 23–39. https://doi.org/10.5406/janimalethics.11.1.0023

Yılmaz, H., Özcan, M., & Şen, E. (2021). Üniversite çalışanlarının sokak köpeklerine yönelik algı ve tutumları: Cinsiyet ve yaş faktörleri. Kafkas Üniversitesi Veteriner Fakültesi Dergisi, 27(3), 457-464.

IMPACT OF MELOXICAM ON OXIDATIVE STATUS IN REPRODUCTIVE TISSUES OF MALE RATS

Assoc. Prof. Dr. Caner ÖZTÜRK

Aksaray University Faculty of Veterinary Medicine, Department of Reproduction and Artificial Insemination, Aksaray, Türkiye

ORCID ID: https://orcid.org/0000-0003-0566-0684

Assoc. Prof. Dr. Neşe Hayat AKSOY

Aksaray University Faculty of Veterinary Medicine, Department of Biochemistry, Aksaray, Türkiye

ORCID ID: https://orcid.org/0000-0001-9039-555X

Lect. Dr. Erkan ÖZKAN

Aksaray University Faculty of Veterinary Medicine, Department of Parasitology, Aksaray, Türkiye

ORCID ID: https://orcid.org/0000-0002-5251-2302

Res. Asst. Ramazan ARSLAN

Aksaray University Faculty of Veterinary Medicine, Department of Reproduction and Artificial Insemination, Aksaray, Türkiye

ORCID ID: https://orcid.org/ 0009-0000-6275-5861

ABSTRACT

Introduction and Purpose: This study aimed to investigate whether meloxicam alters oxidative status in the cauda epididymis and testicular tissues of rats.

Materials and Methods: Six male Wistar rats weighing 220 ± 20 g were used. All animals were housed under controlled conditions, received standard pellet feed and water ad libitum, and were monitored twice daily for general health. The rats were randomly assigned to two groups: the treatment group received meloxicam at 2 mg/kg/day intraperitoneally for five consecutive days, whereas the control group was administered physiological saline via the same route and schedule. At the end of the treatment period, tissue samples were collected and immediately homogenized. Total Antioxidant Status (TAS) and Total Oxidant Status (TOS) were quantified using validated colorimetric methods, and the Oxidative Stress Index (OSI) was calculated from these measurements. Descriptive statistics were generated for each parameter. Depending on distribution characteristics, differences between the control and meloxicam groups were analyzed using either independent samples t-tests or the Mann–Whitney U test.

Results: In the cauda epididymis, meloxicam administration resulted in a marked rise in TAS values compared with the control group ($p < 0.05$). OSI values were significantly lower in the treated animals ($p < 0.05$), while TOS levels did not differ between groups. These findings indicate a shift toward an enhanced antioxidant environment in the epididymal tissue following meloxicam exposure. In contrast, TAS, TOS, and OSI values in testicular tissue showed no significant differences between groups ($p > 0.05$), suggesting that the impact of meloxicam on oxidative regulation may be tissue-specific and more pronounced in the epididymis than in the testis.

Discussion and Conclusion: Overall, short-term meloxicam treatment appears to reinforce antioxidative capacity in the cauda epididymis and may exert a localized protective effect. These results contribute to the understanding of how NSAIDs influence oxidative processes within reproductive tissues and highlight the need for studies with larger sample sizes to further clarify these observations.

Keywords: Meloxicam, Oxidative Stress, Epididymal and Testicular Tissue, Wistar Rat Model

INTRODUCTION

Reactive oxygen species (ROS) are inevitable by-products of aerobic metabolism and play a dual role in male reproductive physiology. At physiological concentrations, ROS participate in normal cellular signaling processes that regulate spermatogenesis, epididymal sperm maturation, capacitation, and acrosome reaction (Agarwal et al., 2014; Dutta et al., 2021). In particular, the epididymis provides a specialized microenvironment where spermatozoa acquire motility and fertilizing capacity under strict redox regulation (O'Flaherty, 2019). However, when ROS production exceeds the buffering capacity of antioxidant defense systems, oxidative stress develops, leading to lipid peroxidation, protein oxidation, and DNA damage in sperm cells, ultimately impairing male fertility (Aitken & Baker, 2006; Agarwal et al., 2014).Oxidative stress in the male reproductive tract is therefore a critical factor in male infertility and is often intertwined with inflammation and other pathologies Dutta et al., 2021).

The epididymis is especially vulnerable to oxidative imbalance because spermatozoa exiting the testis lose the protection of Sertoli cell-derived antioxidants and become reliant on luminal antioxidant mechanisms (O'Flaherty, 2019). Although the testis possesses robust intrinsic antioxidant defenses and a blood–testis barrier that limits exposure to systemic insults, prolonged oxidative stress or pharmacological interference may still disrupt spermatogenesis (Dutta et al., 2021).

Non-steroidal anti-inflammatory drugs (NSAIDs) are widely used in both human and veterinary medicine for their analgesic, antipyretic, and anti-inflammatory properties. Meloxicam is a preferential cyclooxygenase-2 (COX-2) inhibitor that reduces prostaglandin synthesis and inflammatory mediator release (Alemán-Laporte et al., 2022). Prostaglandins play important regulatory roles in testicular blood flow, steroidogenesis, and immune modulation; therefore, COX inhibition may influence reproductive physiology beyond pain control (Uzun et al., 2015). Experimental studies have shown that long-term or high-dose meloxicam exposure can impair spermatogenesis, reduce sperm quality, and induce oxidative damage in testicular tissue (Haroun et al., 2020; Uzun et al., 2015).

Conversely, emerging evidence suggests that under certain conditions, meloxicam may exert protective effects by limiting inflammation-driven ROS production. In large animal models, meloxicam administration has been associated with reduced sperm lipid peroxidation and improved semen quality following inflammatory stress (Gupta et al., 2025). These findings indicate that the impact of meloxicam on oxidative balance may depend on tissue type, dose,

and duration of exposure. Notably, the effects of short-term meloxicam treatment on epididymal oxidative status remain poorly characterized.

Therefore, the present study aimed to investigate whether short-term meloxicam administration alters oxidative stress parameters in the cauda epididymis and testicular tissues of Wistar rats. Total antioxidant status (TAS), total oxidant status (TOS), and the oxidative stress index (OSI) were evaluated to determine whether meloxicam induces tissue-specific modulation of redox balance.

MATERIALS and METHODS

Animals and Experimental Design

Six adult male Wistar rats (body weight 220 ± 20 g) were obtained from the university's laboratory animal center. The rats were housed in standard cages under controlled conditions (12 h light/12 h dark cycle, 23 ± 2°C, with free access to commercial pellet chow and water). Animals were acclimated for one week and monitored twice daily for health and wellbeing. The experiment was conducted in accordance with ethical guidelines for animal research, and all procedures were approved by the Institutional Animal Care and Use Committee. The rats were randomly divided into two equal groups (n = 3 per group) for a 5-day treatment period as follows:

Meloxicam group

Rats received meloxicam at 2 mg/kg/day, administered intraperitoneally for five consecutive days. The meloxicam dosing and schedule were based on prior analgesic regimen studies in rodents adjusted to achieve an anti-inflammatory dose commonly used in laboratory practice.

Control group

Rats received an equivalent volume of physiological saline (0.9% NaCl) via intraperitoneal injection once daily for five days, to account for handling and injection effects. No other treatments were given during this period.

Sample Collection

Twenty-four hours after the final injection (Day 6), rats were anesthetized (ketamine/xylazine overdose, IP) and euthanized. A midline laparotomy was performed, and the reproductive organs were immediately exposed. From each animal, the testes and the cauda epididymides were carefully dissected out. The cauda epididymis (distal region of the epididymis where mature sperm are stored) was chosen because of its importance in sperm storage/maturation and its potential sensitivity to systemic treatments. Tissue samples were gently rinsed in ice-cold saline to remove blood and blotted dry. The supernatants were collected and stored at –80°C until analysis. All preparation steps were carried out quickly to minimize artifactual oxidation.

Biochemical Assays

Total Antioxidant Status (TAS) and Total Oxidant Status (TOS) were measured in tissue homogenate supernatants using validated colorimetric methods. TAS was determined by the automated ABTS radical cation decolorization method described by Erel (2004). In this assay, antioxidants in the sample reduce the blue-green $ABTS^{+}$ radical to a colorless form; the magnitude of decolorization (measured at 660 nm) is proportional to the total antioxidant capacity and is calibrated with Trolox equivalent units.

TOS was measured by the ferrous ion oxidation–xylenol orange (FOX) assay in an automated format according to Erel (2005). In the TOS assay, oxidants present in the sample oxidize ferrous ions to ferric ions, which then bind xylenol orange to produce a colored complex measured at 560 nm; hydrogen peroxide is used as the standard and results are expressed in micromolar H_2O_2 equivalents. For both TAS and TOS assays, we followed kit or literature protocols with appropriate controls and calibrators, and all measurements were performed in duplicate for accuracy.

An *Oxidative Stress Index (OSI)* was calculated to provide an integrated measure of oxidative balance, defined as the ratio of TOS to TAS, expressed as a percentage (OSI = TOS / TAS × 100). In essence, a higher OSI indicates a condition of relatively higher oxidant burden to antioxidant capacity (greater oxidative stress), whereas a lower OSI suggests a more antioxidative or protected state.

Statistical Analysis

Descriptive statistics (mean ± standard deviation) were calculated for TAS, TOS, and OSI in both tissues. Prior to group comparisons, the normality of data distribution was assessed using the Shapiro–Wilk test. TAS and OSI values were found to be normally distributed in both experimental groups, and therefore, differences between groups for these parameters were evaluated using an independent samples t-test. In contrast, TOS values did not meet the assumption of normality in the control group; accordingly, comparisons between the meloxicam-treated and control groups were performed using the non-parametric Mann–Whitney U test. A p value < 0.05 was considered statistically significant for all comparisons.

RESULTS

Oxidative Stress Parameters in the Cauda Epididymis

Descriptive statistics and intergroup comparisons of oxidative stress parameters measured in the cauda epididymal tissue are summarized in Table 1. Total Antioxidant Status (TAS) values were significantly higher in the meloxicam-treated group compared with the control group (2123.19 ± 32.71 vs. 1170.29 ± 215.71 µmol/L, $p < 0.05$).

Total Oxidant Status (TOS) values did not differ significantly between the groups, although a numerical decrease was observed in the meloxicam-treated rats compared with controls (21.40 ± 7.67 vs. 26.67 ± 8.18 µmol/L, $p > 0.05$).

In parallel with the increase in TAS, the Oxidative Stress Index (OSI) was significantly lower in the meloxicam group than in the control group (1.01 ± 0.345 vs. 2.31 ± 0.648, $p < 0.05$), indicating a shift toward a more favorable antioxidative balance in the cauda epididymal tissue following meloxicam administration.

Table 1. Descriptive statistics and intergroup comparisons of oxidative stress parameters (TAS, TOS, and OSI) measured in the cauda epididymal tissue of control and meloxicam-treated rats.

Group	TAS (µmol/L) (Mean ± SD)	TOS (µmol/L) (Mean ± SD)	OSI (Mean ± SD)
Control	1170.29 ± 215.71	26.67 ± 8.18	2.31 ± 0.648
Meloxicam	2123.19 ± 32.71	21.40 ± 7.67	1.01 ± 0.345
	*	-	*

* Indicates a statistically significant difference compared with the control group ($p < 0.05$).

Oxidative Stress Parameters in Testicular Tissue

The descriptive statistics and group comparisons of oxidative stress parameters measured in testicular tissue are presented in Table 2. No statistically significant differences were detected between the meloxicam-treated and control groups for TAS, TOS, or OSI values ($p > 0.05$ for all comparisons).

Although TAS values tended to be higher and OSI values tended to be lower in the meloxicam-treated group compared with controls, these differences did not reach statistical significance. Testicular TOS values were also comparable between the groups. Overall, short-term meloxicam administration did not significantly alter the oxidative status of testicular tissue under the conditions of the present study.

Table 2. Descriptive statistics and intergroup comparisons of oxidative stress parameters (TAS, TOS, and OSI) measured in testicular tissue of control and meloxicam-treated rats.

Group	TAS (µmol/L) (Mean ± SD)	TOS (µmol/L) (Mean ± SD)	OSI (Mean ± SD)
Control	1429.71 ± 689.55	6.84 ± 0.37	0.542 ± 0.398
Meloxicam	2248.55 ± 80.12	6.32 ± 2.73	0.309 ± 0.009
	-	-	-

DISCUSSION

Our pilot data suggest a tissue-specific redox response to short-term meloxicam exposure. Meloxicam increased TAS and reduced OSI in the cauda epididymis, indicating a shift toward an enhanced antioxidant environment in this compartment. In contrast, TAS, TOS, and OSI in testicular tissue did not differ significantly between groups, although numerical trends were observed. Together, these findings imply that the epididymis may be more responsive to short-term COX inhibition–related modulation of oxidative balance than the testis under baseline (non-inflammatory) conditions.

Our study adds to a growing body of literature indicating that nonsteroidal anti-inflammatory drugs (NSAIDs) can influence oxidative stress and reproductive health in males. Uzun et al. (2015) reported that subchronic meloxicam treatment in rats significantly depressed testicular antioxidant defenses – including reduced activities of superoxide dismutase (SOD), catalase, glutathione peroxidase (GPx), and glutathione levels – accompanied by histopathological damage to the seminiferous tubules. In their work, meloxicam (as well as naproxen, another NSAID) led to decreased sperm count and motility and clear structural injury in the testes without altering systemic hormone levels. Our observations of increased OSI and altered TAS/TOS in the testes are consistent with this mechanism suggesting that even short-term COX-2 inhibition can tip the pro-oxidant/antioxidant balance towards oxidative stress in testicular tissue. Notably, Haroun et al. (2020) likewise found that chronic high-dose meloxicam (8 mg/kg for 63 days) induced marked testicular toxicity in rats, characterized by decreased testis weight, impaired sperm parameters, and diminished antioxidant activity in the testis, along with severe tubular degeneration. Co-administration of the antioxidants curcumin or ascorbic acid effectively mitigated these changes, reinforcing the notion that meloxicam's deleterious effects on the testis are largely mediated by oxidative stress and can be counteracted by bolstering antioxidant defenses.

The epididymal findings from our study merit discussion in light of the epididymis's unique role and protection mechanisms. The epididymis is richly endowed with enzymatic antioxidants – including SOD, CAT, GPx (such as the secreted GPX5), peroxiredoxins, and others – which collectively maintain a low ROS environment vital for sperm maturation. This robust antioxidant system is evolutionarily tuned to shield maturing spermatozoa from oxidative damage during their transit and storage in the epididymis (O'Flaherty, 2019). It is therefore notable that short-term meloxicam did not provoke as large a shift in OSI in the epididymis as in the testis (as suggested by our tissue-specific data). One interpretation is that the epididymal antioxidant network may buffer against transient oxidative perturbations, rendering the epididymal tissue more resilient to a 5-day meloxicam exposure. However, evidence from longer exposures indicates that the epididymis can indeed be adversely affected by NSAID-induced oxidative stress. For instance, Owumi et al. (2020) showed that a 14-day course of diclofenac in rats elevated lipid peroxidation and ROS/RNS levels and diminished antioxidant enzyme activities in both epididymal and testicular tissues. Such oxidative stress resulted in impaired sperm parameters and lower serum testosterone, whereas selenium co-treatment prevented these effects by suppressing nitrosative and oxidative stress in the reproductive tract. Similarly, Rodrigues et al. (2024) reported that oral meloxicam (1 mg/kg for 15 days) significantly reduced serum testosterone and sperm production, and lowered sperm counts in the proximal epididymal regions (caput/corpus) of rats. Interestingly, meloxicam in that study did not change cauda epididymal sperm count but did delay sperm transit and attenuate noradrenaline-induced contractions of the distal epididymal duct. Taken together, these findings indicate that while the epididymis has potent antioxidant safeguards, NSAID exposure (including meloxicam) can still disrupt epididymal function – whether via direct oxidative damage or indirectly through altered androgen levels and smooth muscle activity. The relatively modest oxidative changes we observed in the epididymis after 5 days of meloxicam may therefore represent the early stages of a process that, with prolonged exposure, could culminate in significant epididymal oxidative injury and functional deficits.

It is also important to consider the interplay between inflammation, ROS generation, and the antioxidant response in our model. Under physiological conditions, the testes exhibit an immune-privileged status with controlled inflammatory activity, whereas acute inflammatory insults can trigger significant ROS production and tissue damage. By virtue of its anti-inflammatory action, meloxicam might be expected to *reduce* oxidative stress in scenarios where inflammation is a driving factor (e.g. infection, torsion, or ischemia-reperfusion injuries). In line with this, therapeutic COX-2 inhibition has shown protective effects in models of testicular torsion – an extreme case of inflammation and oxidative injury. Gürocak et al. (2011) observed that meloxicam treatment attenuated tissue damage in an experimental torsion/detorsion model, significantly lowering malondialdehyde (MDA) levels (a lipid peroxidation marker) in ischemic testes. They concluded that aggressive management of the inflammatory response (including use of a COX-2 inhibitor like meloxicam) helps salvage testicular tissue by curbing inflammation-induced oxidative stress. Similarly, COX inhibitors such as ibuprofen have been reported to reduce oxidative injury in acute testicular ischemia-reperfusion when given prophylactically (Dokmeci et al., 2007; Özgür et al., 2022). These findings underscore a nuanced context-dependence: in pathological inflammatory states, meloxicam's antioxidant effect (via dampening inflammation) can outweigh its potential pro-oxidant side effects, resulting in net protection. In our study, however, healthy rats were treated in the absence of any overt inflammatory challenge. Under such normal conditions, systemic COX-2 inhibition may offer little anti-oxidative benefit and can instead tilt the balance toward oxidative stress by disrupting normal prostaglandin-mediated homeostasis. It is conceivable that in our short-term regimen, meloxicam induced a mild "oxidative inflammation" at the cellular level perhaps by subtle activation of immune cells or by causing transient drops in

antioxidant enzyme expression – even though no clinical inflammation was present. Indeed, the testis contains resident macrophages and germ cells that can produce ROS; altering the COX-2/PGE_2 axis might influence these cells' redox signaling and lead to an accumulation of oxidants.

CONCLUSION

In conclusion, short-term meloxicam administration appears to reinforce antioxidative capacity in the cauda epididymis, while no statistically significant changes were detected in testicular oxidative status under the present conditions. Given the limited sample size, these findings should be considered preliminary and warrant confirmation in larger, mechanistically oriented studies.

REFERENCES

Agarwal, A., Virk, G., Ong, C., & du Plessis, S. S. (2014). *Effect of oxidative stress on male reproduction*. World Journal of Men's Health, 32(1), 1–17. https://doi.org/10.5534/wjmh.2014.32.1.1

Aitken, R. J., & Baker, M. A. (2006). *Oxidative stress, sperm survival and fertility control*. Molecular and Cellular Endocrinology, 250(1–2), 66–69. https://doi.org/10.1016/j.mce.2005.12.026

Aitken, R. J., Drevet, J. R., Moazamian, A., & Gharagozloo, P. (2022). *Male infertility and oxidative stress: A focus on the underlying mechanisms*. Antioxidants, 11(2), 306. https://doi.org/10.3390/antiox11020306

Alemán-Laporte, J., Alvarado, G., Antiorio, A. T. F. B., Trías, J. F., Rojas-Carvajal, M., & Mori, C. M. C. *et al.* (2022). *Effect of the analgesics dipyrone, tramadol, and meloxicam on the behavior of laboratory rats*. Journal of Veterinary Behavior, 57, 24–30. https://doi.org/10.1016/j.jveb.2022.08.001

Dokmeci, D., Kanter, M., Inan, M., Aydogdu, N., Basaran, U. N., Yalcin, O., & Turan, F. N. (2007). Protective effects of ibuprofen on testicular torsion/detorsion-induced ischemia/reperfusion injury in rats. *Archives of toxicology*, *81*(9), 655-663.

Dutta, S., Sengupta, P., Slama, P., & Roychoudhury, S. (2021). Oxidative Stress, Testicular Inflammatory Pathways, and Male Reproduction. *International Journal of Molecular Sciences*, *22*(18), 10043. https://doi.org/10.3390/ijms221810043

Erel, O. (2004). A novel automated direct measurement method for total antioxidant capacity using a new generation, more stable ABTS radical cation. Clinical Biochemistry, 37(4), 277–285. https://doi.org/10.1016/j.clinbiochem.2003.11.015

Erel, O. (2005). A new automated colorimetric method for measuring total oxidant status. Clinical Biochemistry, 38(12), 1103–1111. https://doi.org/10.1016/j.clinbiochem.2005.08.008

Gupta, V. K., Mohanty, T. K., Bhakat, M., Baithalu, R. K., Kumar, N., Dewry, R. K., Nain, D., Soe, A., & Arunkumar, R. (2025). Meloxicam and levamisole administration ameliorates FMD vaccination stress on frozen semen attributes in Sahiwal bulls. Scientific Reports, 15, 11863. https://doi.org/10.1038/s41598-024-81460-5

Gürocak, S., Yilmaz, A., Alp, E., Ure, I., Sozen, S., Menevse, S., Menevse, A., & Bozkirli, I. (2011). *Inflammation and oxidative stress in testicular torsion: Do they deserve intensive*

treatment to save both guilty and innocent testes? Urology, 78(1), 164–169. https://doi.org/10.1016/j.urology.2010.12.069

Haroun, M. R., Eldin, A. A., El-Khouly, S. M., & Mostafa, I. A. (2020). The protective effect of ascorbic acid and curcumin on the chronic toxicity of meloxicam on the testis of adult albino rats. Benha Journal of Applied Sciences, 5(5), 1–19. https://doi.org/10.21608/bjas.2020.136691

O'Flaherty, C. (2019). Orchestrating the antioxidant defenses in the epididymis. Andrology, 7(5), 662–668. https://doi.org/10.1111/andr.12630

Owumi, S. E., Aliyu-Banjo, N. O., & Odunola, O. A. (2020). *Selenium attenuates diclofenac-induced testicular and epididymal toxicity in rats*. Andrologia, 52(9), e13669. https://doi.org/10.1111/and.13669

Özgür, B. C., Sürer, H., Yücetürk, C. N., Karakan, T., Özer, E., & Öğüş, E. (2022). The protective effect of roflumilast and ibuprofen on testicular ischemia reperfusion injury: An experimental study. *Turkish Journal of Trauma & Emergency Surgery*, *28*(6), 730.

Rodrigues, R. T. G. A., Marques, V. B., da Silva, M. S., Gomes, L. T. C., de Sena, M. O., Figueiredo, B. S., Oliveira, J. I. N., Gavioli, E. C., de Menezes, D. J. A., & da Silva Junior, E. D. (2024). *Negative effects of ketoprofen and meloxicam on distal cauda epididymal duct contractions, testosterone levels, and sperm count in rats*. Reproductive Biology, 24(4), 100963. https://doi.org/10.1016/j.repbio.2024.100963

Uzun, B., Atli, O., Perk, B. O., Burukoglu, D., & Ilgin, S. (2015). *Evaluation of the reproductive toxicity of naproxen sodium and meloxicam in male rats*. Human & Experimental Toxicology, 34(4), 415–429. https://doi.org/10.1177/0960327114542886

4rd INTERNATIONAL PARIS CONGRESS ON AGRICULTURE AND ANIMAL HUSBANDRY

December 18-21, 2025/ Paris, France

28.12.2025

REF: Akademik Teşvik

İlgili makama;

4. Uluslararası Paris Tarım Ve Hayvancılık Kongresi, 18-21 Aralık 2025 tarihleri arasında Paris Fransa'da 11 farklı ülkenin (Türkiye 28 bildiri- Diğer ülkeler 38 bildiri) akademisyen/araştırmacılarının katılımıyla gerçekleşmiştir

Kongre 16 Ocak 2020 Akademik Teşvik Ödeneği Yönetmeliğine getirilen "Tebliğlerin sunulduğu yurt içinde veya yurt dışındaki etkinliğin uluslararası olarak nitelendirilebilmesi için Türkiye dışında en az beş farklı ülkeden sözlü tebliğ sunan konuşmacının katılım sağlaması ve tebliğlerin yarıdan fazlasının Türkiye dışından katılımcılar tarafından sunulması esastır." değişikliğine uygun düzenlenmiştir.

Bilgilerinize arz edilir,

Saygılarımla

Dr. Yusuf Hassan
Committee Member

İKSAD ENSTİTÜSÜ
Çankaya – Ankara
06-146-071

Konu : Kongre Düzenlenmesi
Sayı : BSE-2 5 Aralık 2025

İLGİLİ KURUMA

İçişileri Bakanlığı tarafından tahsis edilen 06-146-071 tescil kodu ile Tüzel Kişiliğe sahip olan İKSAD Enstitüsü 5253 sayılı kanuna uygun olarak "Bilimsel araştırmalar ve akademik çalışmalar" alanında ulusal ve uluslararası düzeyde faaliyetlerini yürütmektedir.

Kurumumuzun Yönetim Kurulu 10 Nisan 2025 tarihinde saat 10.30'da "Bilimsel Diplomasi Projesi" görüşmeleri ile "Bilimsel Kongreler Düzenlenmesi" gündemleri ile toplanmış ve alınan (2 numaralı) karara istinaden aşağıda detayları yazılı olan bilimsel etkinliğin düzenlenmesine ve etkinliğe ilişkin resmi görevlendirme konusunda karar vermiştir.

Bilgi ve gereğini rica ederim

Dr. Mustafa Latif EMEK
Yönetim Kurulu adına

Etkinlik Adı: 4th INTERNATIONAL PARIS CONGRESS ON AGRICULTURE & ANIMAL HUSBANDRY
Etkinlik Tarihi ve Yeri: 18-21 Aralık 2025, Paris

DÜZENLEME KURULU
Dr. Yusuf Hassan - Umaru Musa Yar'adua University
Dr. Mehmet Fırat BARAN - Siirt University, Faculty of Agriculture, Türkiye
Dr. Zubair ASLAM - University of Agriculture, Department of Agronomy, Pakistan
Dr. Nurlan Akhmetov - Ahmet Yesevi University, Kazakhstan
Dr. Yusuf Hassan - Umaru Musa Yar'adua University, Nigeria
Dr. Germán Martínez Prats - Universidad Juárez Autónoma de Tabasco, México
Dr. Rafael Ricardo Renteria Ramos - Universidad Abierta y a Distancia UNAD, Colombia

Etkinlik linki: https://www.iksadparis.org/agriculture