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Research Articles

1. Molecular Insight on Phylogeny and Systematics of the Narrowly Endemic Centaurea bingoelensis (Asteraceae)
Ferit Can Yazdıç , Neslihan Taşar , Mikail Açar , İbrahim Seyfettin Çelik , Uğur Çakılcıoğlu
Page: 543-551

2. Molecular characterization of some peach and nectarine hybrids by ISSR and SSR markers
Aycan Bayav , Dicle Dönmez , Songul Comlekcioglu , Ayzin Küden , Yıldız Aka Kaçar
Page: 552-564

3. Performance of Ready-To-Use Isothermal Detection Kits in Plum pox virus (PPV) Detection
Khalid Rasooly , Songül Yalçın Ateş , Burak Özgören , Ali Ferhan Morca , Ali Çelik
Page: 565-573

4. Comparison of Total Phenolic Contents and Antioxidant Activities of Ripe and Unripe Fig (Ficus carica L.) Extracts Using Different Solvents
Zeynep Doğru , Mehmet Akbulut , Hüsamettin Vatansev , Serdar Karakurt
Page: 574-584

5. Determination of Relationships Between Colour Indices and Colour Parameters in Dried Persimmon Slices
Begüm Arkain , Habib Kocabıyık
Page: 585-595

6. Household Level Analysis of Rural-to-Urban Migration in Türkiye
Gülistan Erdal , Adnan Çiçek , Hilmi Erdal , Rüştü Yayar , Bekir Ayyıldız
Page: 596-612

7. Impact of GA3 Application at Different Times and Methods on Tomato Growth and Fruit Shelf Life
Hakan Başak , Gamze Çakırer Seyrek , Özge Horzum , Köksal Demir
Page: 613-626

8. Current Status of Flock Management, Care and Feeding Practices in Fattening Sheep Farms in Karacabey District
Ömer Şengül
Page: 627-639

9. Determination of Factors Affecting Net Profit in Buffalo Milk Production by Different Data Mining Algorithms: A Case Study of Iğdır Province
Köksal Karadaş , Osman Doğan Bulut , Hakan Duman
Page: 640-652

10. Forecasting the Power Output of Photovoltaic Systems Using Ant Colony Optimization and Determining the Optimal Time Interval for Agricultural Use
Şaban Fındık , Salih Ermiş
Page: 653-665

11. Evaluating the Effects of Utilitarian and Hedonic Drivers on Milk Consumption: A Structural Equation Modeling Approach
Yavuz Topcu
Page: 666-678

12. Comparative Performance Analysis of Deep Learning Based CNN Models for Diagnosis of Corn Leaf Diseases
Adnan Gökten , Erkut Tekeli
Page: 679-686

13. The Impact of Green Economy Approaches on Marketing in The Sugar and Confectionery Industry: The Case of Konya Province
Gürhan Özaydın
Page: 687-695
Research Article
14. Economic and Agricultural Effects of Climate Change on Forage Crop Yield in Erzurum Province: ARDL Bound Test Approach
Tuba Karabacak , Melih Okcu
Page: 696-704

15. Responses of Some Bread Wheat (Triticum aestivum L.) Cultivars to Salinity Stress During Germination and Early Seedling Development Stages
İrem Uçan , Mevlüt Akçura
Page: 705-715

16. Isolation and Characterization of Bacillus spp. Producing Indole-3-Acetic Acid (IAA) and Solubilizing Inorganic Phosphate from the Rhizosphere of Medicinal Sage (Salvia officinalis)
Murat Güler
Page: 716-726

17. Determination of Some Nutrient Contents of Endemic Plant Verbascum yurtkuranianum (Schrophulariaceae)
Ferrin Ferda Aşık
Page: 727-732

18. Comparative Analysis of Trend Models for Standardized Precipitation Index (SPI) Data for Çanakkale
Nazlı Çiçek Söylemez , Ünal Kızıl
Page: 733-742

19. Determination of Genotype × Environment Interaction for Seed Yield in Oilseed Flax (Linum usitatissimum L.) Genotypes
Şahinde Küçük , Mevlüt Akçura
Page: 743-752

20. Optimization of Sodium Azide Application in Black Cumin (Nigella sativa L.) and Determination of Agronomic Characteristics in M1 Generation
Hivrun Turanlı , Furkan Çoban , Kamil Haliloğlu
Page: 753-763

21. Trakya Bölgesi Doğal Florasında Belirlenen Önemli Bazı Yabani Fiğ (Vicia spp.) Türlerinin Ekolojik Dağılımı ile Verim ve Verim Özelliklerinin Belirlenmesi
Adnan Orak , Canan Şen , İlker Nizam , Necmettin Güler , Hüseyin Ersoy , Hazım Serkan Tenikecier
Page: 764-782

22. Contribution to the Knowledge of the Acaenitinae and Diplazontinae (Hymenoptera: Ichneumonidae) fauna of Elazığ Province in Eastern Türkiye
Saliha Çoruh , Yeşim Bulak Korkmaz
Page: 783-789

23. Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü (TAGEM) Tarafından Geliştirilen Buğday Çeşitlerinin Üretici Memnuniyeti Açısından Değerlendirilmesi; Kahramanmaraş, Mersin, Adana ve Sivas İli Örneği
Ahmet Akdoğan , Ezgi Çimen Ünlükal , Cumalı Çakirli , Rahmi Taşcı
Page: 790-801

24. The Impact of Agricultural Financialization on Agricultural Output: The Case of Türkiye
Mustafa Baylan
Page: 802-811

25. The Asymmetric Effects of Agricultural Policy Support on Agricultural Employment in Türkiye: A NARDL Approach
Zekiye Şengül Abedı
Page: 812-831

26. The Effects of Hot and Cold Infusions on Some Quality Characteristics and Bioactivity of Walnut (Juglans regia L.) Leaf Tea Enriched with Different Spices
Mehmet Ali Salık
Page: 832-844

27. Landscape Design Process and Implementation for Detached House Gardens Suitable for Continental Climates
Ahmet Caf

Page: 845-854

28. Türkiye Florasındaki Dorycnium Miller (Fabaceae) Cinsinin Taksonomik Özellikleri ve Morfolojisi
Yusuf Ziya Kocabaş , Ahmet İlçim
Page: 855-869

29. Antagonists for the Control of Botrytis cinerea in Tomatoes: An In Vitro Evaluation and In Silico Screening By Molecular Docking of Possible Inhibitors
Tuba Genç Kesimci , Mustafa Akbaba , Serap Demirel
Page: 870-886

30. Marketing Strategies of Food and Beverage Companies in the ISO 500 List: A Study on Their Websites
Berkay Keskin
Page: 887-897

31. The Effect of Aronia Pulp Addition Instead of Wet Brewers Grain Pulp in Total Mixed Ration on In Vitro Gas Production Technique Parameters
Harun Emre Solmaz , Kadir Erten , Fisun Koc
Page: 898-909

32. Agriculture in Türkiye Under Drought Threat: A SWOT Analysis Based on Expert Views
Veysi Kortak , Özlem Çakır
Page: 910-929

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Original Article

Molecular Insight on Phylogeny and Systematics of the Narrowly Endemic *Centaurea bingoelensis* (Asteraceae)

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ABSTRACT

Centaurea L. is a genus that is systematically discussed and whose taxonomic issues need to be clarified in the light of molecular techniques developed in recent years. This study aims to contribute taxonomically in molecular terms by studying the morphological and phylogenetic relationships of *Centaurea bingoelensis*. This limited, endemic species grows naturally in the Bingöl province of Türkiye. A phylogenetic analysis based on the molecular marker ITS, which is the most preferred in evolutionary studies and found in nuclear DNA, has been proposed as a molecular marker of *C. bingoelensis* , an endemic plant in Türkiye, and has not yet been molecularly identified. For this purpose, PCR amplification of the fragment mentioned above was performed, followed by direct sequencing, analysis of nucleotide variation, and phylogenetic analysis with different species. The *Centaurea* species identified so far have been shown to have three main distinct major clades and the specific phylogenetic methods used (NJ, ML, MP) and the ITS nucleotide sequences analyzed revealed a close phylogenetic relationship between *C. bingoelensis* and *C. spectabilis*. For a more accurate phylogenetic classification of this species within the Asteraceae family, their close relationships were probed using similar sequences from the GenBank Database. Phylogenetic analysis of *C. bingoelensis* specimens using ITS sequences reveals their position in the Asteraceae family and molecular support for these specimens being new species as proposed. Although morphologically similar to *C. fenzlii* and *C. obtusifolia*, the remarkable point of our study is that *C. bingoelensis* is phylogenetically closer to *C. spectabilis*. This work has exciting implications for understanding the evolution and diversification of the genus *Centaurea*. In addition, the results of this study show that the samples identified as *Centaurea* species in Türkiye are still not entirely determined genetically.

Key words: Endemic, Compositae, ITS, Systematic, Phylogeny

Dar Yayılışlı Endemik *Centaurea bingoelensis'in* (Asteraceae) Filogenisi ve Sistematiğine Moleküler Bakış

ÖZ

Centaurea L. sistematik olarak tartışılan ve son yıllarda gelişen moleküler teknikler ışığında taksonomik sorunların açıklığa kavuşturulması gereken bir cinstir. Bu çalışma *Centaurea bingoelensis* Behçet & İlçim türünün morfolojik ve filogenetik ilişkilerini inceleyerek moleküler açıdan taksonomik katkı sağlamayı amaçlamaktadır. Bu sınırlı endemik tür, Türkiye'nin Bingöl ilinde doğal olarak yetişmektedir. Türkiye'de endemik bir bitki olan ve henüz moleküler olarak tanımlanmamış olan *C. bingoelensis* için evrimsel çalışmalarda en çok tercih edilen ve nükleer DNA'da bulunan ITS moleküler markörüne dayalı bir filogenetik analiz önerilmiştir. Bu amaçla, yukarıda

bahsedilen parçanın PCR amplifikasyonu gerçekleştirilmiş, ardından doğrudan dizileme, nükleotid varyasyonunun analizi ve farklı türlerle filogenetik analiz yapılmıştır. Bu türün Asteraceae familyası içinde daha doğru bir filogenetik sınıflandırması için, Gen Bank veri tabanındaki benzer diziler kullanılarak yakın ilişkileri araştırılmıştır. Şu ana kadar tanımlanan *Centaurea* türlerinin üç ana belirgin klada sahip olduğu ve kullanılan spesifik filogenetik yöntemlerin (NJ, ML, MP) ve analiz edilen ITS nükleotid dizilerinin *C. bingoelensis* ve *C. spectabilis* arasında yakın bir filogenetik ilişki olduğunu ortaya koyduğu gösterilmiştir. *C. bingoelensis* örneklerinin ITS dizileri kullanılarak yapılan filogenetik analiz sonuçları, bu türün Asteraceae familyasındaki konumunu ve yeni tür olma olasılığını moleküler açıdan desteklemektedir. Morfolojik olarak *C. fenzlii* ve *C. obtusifolia* türüne benzemekle birlikte, çalışmamızın dikkat çekici noktası *C. bingoelensis* türünün filogenetik olarak *C. spectabilis* türüne daha yakın olmasıdır. Bu çalışma, *Centaurea* cinsinin evrimini ve çeşitlenmesini anlamak için heyecan verici çıkarımlara sahiptir. Ayrıca bu çalışmanın sonuçları, Türkiye'de *Centaurea* türü olarak tanımlanan örneklerin genetik olarak hala tam olarak belirlenemediğini göstermektedir.

Anahtar kelimeler: Endemik, Compositae, ITS, Sistematik, Filogeni

INTRODUCTION

The genus *Centaurea*, one of the important genera of the Asteraceae family, is a systematically problematic genus distributed worldwide and includes approximately 700 species in Asia, North Africa, America, and Europe (Güner et al., 2012). Türkiye is one of the centers of genetic differentiation for the genus *Centaurea*. *Centaurea*, the third largest genus of the flora of Türkiye, has 219 species and 131 of them are endemic (Ozbek, 2021; Uysal, 2012). It is one of the genera with the highest number of endemic taxa. The endemism rate is approximately 59%. The systematics of the genus *Centaurea* has changed, especially with the development of molecular techniques, and thus some problems have been solved. In the light of these studies, it is known that Türkiye is an essential speciation center of the genus *Centaurea*, with many rare endemic species as evidenced by ITS-based molecular data (Médail and Diadema, 2009). For this reason, *Centaurea* constitutes an excellent model for analyzing speciation and diversification processes in the region (López-Pujol et al., 2016). *Centaurea* is also a genus that can be useful for determining gene flow between species and providing insights into the history of the species (Hilpold et al., 2014; Garcia-Jacas et al., 2009).

As a result of ongoing developments in the field of plant molecular systematics, DNA sequence analysis studies have been started to reveal the spectrum of all taxonomic levels and to provide solutions (Soltis et al., 1992). In the last decade, several molecular studies based on the ITS barcode or microsatellite marker for taxonomic identification have been published to investigate genetic diversity and relationships among *Centaurea* (Atia et al., 2021). More recently, Doğan et al. (2015) used ISSR markers to resolve genetic relationships within taxonomic entities of *Centaurea* species, including those considered taxonomically incorrect, such as *C. ptosimopappoides* Wagenitz and *C. straminicephala* Hub.-Mor. (Syn. *Psephellus straminicephalus* (Hub.-Mor.) Wagenitz). They concluded that it was a powerful tool. In addition, Yıldırım et al. (2009), in a study examining genetic relationships among 16 *Centaurea* species, concluded that the RAPD marker system was appropriate when compared to fatty acid methyl ester (FAME) profiles in species in the Eastern Anatolia Region of Türkiye.

As the number of species increases, it becomes increasingly difficult to classify them. *Centaurea* is a taxonomically complex genus, as it contains many species that differ significantly in morphology. In their study, researchers defined *Centaurea bingoelensis* as a new species. They stated that it was similar to *C. fenzlii* and especially to *C. obtusifolia* in terms of leaf structure (Behçet et al., 2017). As a result of their detailed systematic studies, they definitively revealed that it is a distinct species. However, this study dealt with the relationships between taxa based on morphology. Considering the distribution areas of the taxa, *C. fenzlii* is distributed in eastern Anatolia, *C. obtusifolia* is distributed in east-southeast Anatolia, *C. spectabilis* is distributed in eastern Anatolia, while *C. bingoelensis* is found in an area where the distributions of these taxa intersect. In addition, studies have shown that this species, which lives on rocky slopes, is among those at risk of extinction if not protected due to grazing and erosion. For this reason, molecular analyses to be conducted for the first time on this species are important for understanding the systematics of both the genus and species. These analyses also aim to support and complement the existing morphological data. The absence of a comprehensive, well-resolved, and well-supported phylogeny for *Centaurea* is primarily due to the fact that most existing studies are based on relatively small subsets of species and rely on only one or, at most, a few genes or other character sets (e.g., morphology or karyology). Studies using modern systematic methods are critical in determining the degree of relatedness among species and in identifying endemic taxa, if present. To overcome these limitations, all available DNA sequence data of species in this family were pooled and analyzed. *C. bingoelensis* is a rare, narrowly distributed local endemic species found in a limited region of eastern Anatolia (Bingöl province, from

which it is named) in Türkiye. So far, no studies have been conducted on the molecular taxonomy and variation of *C. bingoelensis* , apart from basic ITS-based morphological characterization and identification. In addition, according to Uysal et al. (2021), it is a plant with strong potential for new phyto-pharmacological studies. This study aims to evaluate the phenotypic variation of *C. bingoelensis*, a local endemic species with high pharmacological potential and endangered status, and to evaluate the position of the species in the genus based on the nucleotide sequences of the internal transcribed spacer (ITS) region, which includes nuclear ribosomal DNA.

MATERIALS AND METHODS

Plant specimens

The specimens of thestudied species were collected in the Genç district of Bingöl province (Türkiye) during the flowering period (Figure 1). The collected specimens were prepared as herbarium material for morphological research and are kept in the laboratories of Munzur University for further studies. The studied specimen of *C. bingoelensis* were collected from B8 Bingöl (Türkiye), Genç district, Çötele (çotla) highland roadsides, on 10 June 2020, at an altitude of 1900-2050 m (collector no: UC 20-15).

Figure 1. Photographs from the natural habitat of *C. bingoelensis* (Photo: M.Maruf Balos)

Isolation of DNA

Genomic DNA was isolated from young leaves by the hexadecyltrimethylammonium bromide (CTAB) method as modified by Doyle and Doyle (1990). For each individual, 100 mg of ground leaf tissue was suspended in 500 µl extraction buffer (20 mM EDTA, 0.1 M Tris-HCl (pH 8.0), 1.4 M NaCl, 2% (w/v) CTAB and 5 µl β-mercaptoethanol). The suspension was mixed well and incubated at 60°C for 30 minutes, followed by chloroform-isoamyl alcohol (24:1) extraction and precipitated with 0.75 volumes of isopropanol at -20°C. After centrifugation at low speed for 5 minutes, the resulting pellet was washed with 70% (v/v) ethanol and 10 mM ammonium acetate. DNA was then suspended in TE buffer. The resulting DNA concentration was assessed by electrophoresis on a 1% agarose gel and stained with ethidium bromide.

PCR amplification and sequencing

PCR amplification of the samples was carried out using the primers ITS5a_F (5’-CCTTATCATTTAGAGGAAGGAG-3’) and ITS4_R (5’-TCCTCCGCTTATTGATATGC-3 (White et al. 1990; Stanford et al. 2000). These primers amplify the ITS region of approximately600-700 bp in length. The PCR reaction was performed in a thermal cycler (BIO-RAD). The reaction mixture consisted of 40 µl of 500 ng genomic DNA, 2.5 U of Taq DNA polymerase, 5 µl of 10 X Taq buffer (100 mM Tris-HCl, 500 mM KCl pH-8.3), 200 µM dNTP, 10 pmol of each primer. Amplification included an initial denaturation at 95°C for 5 minutes, followed by 35 cycles of denaturation at 94°C for 1 minute, annealing at 55°C for 1 minute, , and extension at 72°C for 1 minute. PCR products were visualized under a transilluminator after electrophoresis on a 1.5% agarose gel-stained ethidium bromide, using 5 µl of the amplified product.

DNA sequencing and phylogenetic analyses

PCR products were submitted to Iontek Laboratories (Istanbul, Türkiye) for Sanger sequencing using the BigDye® Terminator v3.1 Cycle Sequencing Kit (Applied Biosystems, Life Technologies Corporation, Austin, TX,

USA).Bidirectional sequencing was conducted using primers specific to the ITS1-5.8S-ITS2 regions. Sequence alignment and data analysis were performed using ChromasPro V1.34 and Clone Manager 10, respectively. Similarity analysis was carried out using Clustal Omega (https://www.ebi.ac.uk/Tools/msa/clustalo/). In addition to the sequences obtained in this study, reference taxa used in the phylogenetic analysis were retrieved from GenBank (http://www.ncbi.nlm.nih.gov/), and the original publications and accession numbers of these sequences were provided in Supplementary material for sequence.

The nucleotide sequences of the ITS1-5.8S-ITS2 regions were aligned using BioEdit v7.2.5 software (Hall, 1999) and the CLUSTAL-W algorithm (Thompson et al. 1994). The evolutionary distances were computed using the Maximum Composite Likelihood method (Tamura et al., 2004), and phylogenetic trees were constructed using the Neighbor-Joining (NJ) (Saitou and Nei, 1987), Maximum Likelihood (ML) and Maximum Parsimony (MP) methods in MEGA X (Kumar et al. 2018). Tree topologies were evaluated using bootstrap analysis with 1,000 replications (Felsenstein, 2004), and *Astragalus mongholicus* (AF359750.1) was used as the outgroup. The resulting trees were visualized using the Interactive Tree of Life (iTOL) webserver (http://itol.embl.de/) (Letunic and Bork, 2016). All other parameters followed default settings.

RESULTS AND DISCUSSION

The molecular and phylogenetic analyses conducted in this study aimed to clarify the taxonomic status and evolutionary relationships of the local endemic species *C. bingoelensis.* Analyses were based on ITS region sequences obtained from two individual samples (T1 and T2) collected from the natural habitat of species. The resulting sequence data were submitted to the NCBI GenBank databases and assigned accession numbers OM905073.1 (for T1) and OM905074.1 (for T2).

Phylogenetic analyses produced similar topologies using the NJ, ML, and MP methods, therefore the results were presented as a single consensus tree (Figure 2). All trees generated by the NJ, MP, and ML methods are showed bootstrap values exceeding 40%, and to improve reliability, only branches with support values above 50% were considered. Bootstrap values greater than 50% are indicated in the Figure 2 and 3. The sequence analyzes of Centaurea-T1 and T2 revealed high similarity to *C. spectabilis* (GenBank Access. No: DQ319164). Both Centaurea-T1 and T2 formed clades strong support, as indicated by bootstrap values exceeding 50% across multiple phylogenetic models: 61% under the Jukes-Cantor(JC69) model, 63% under the Tamura-Nei model with a gamma distribution (TN93+G) and 89% under the MP method (Figure 2-3).

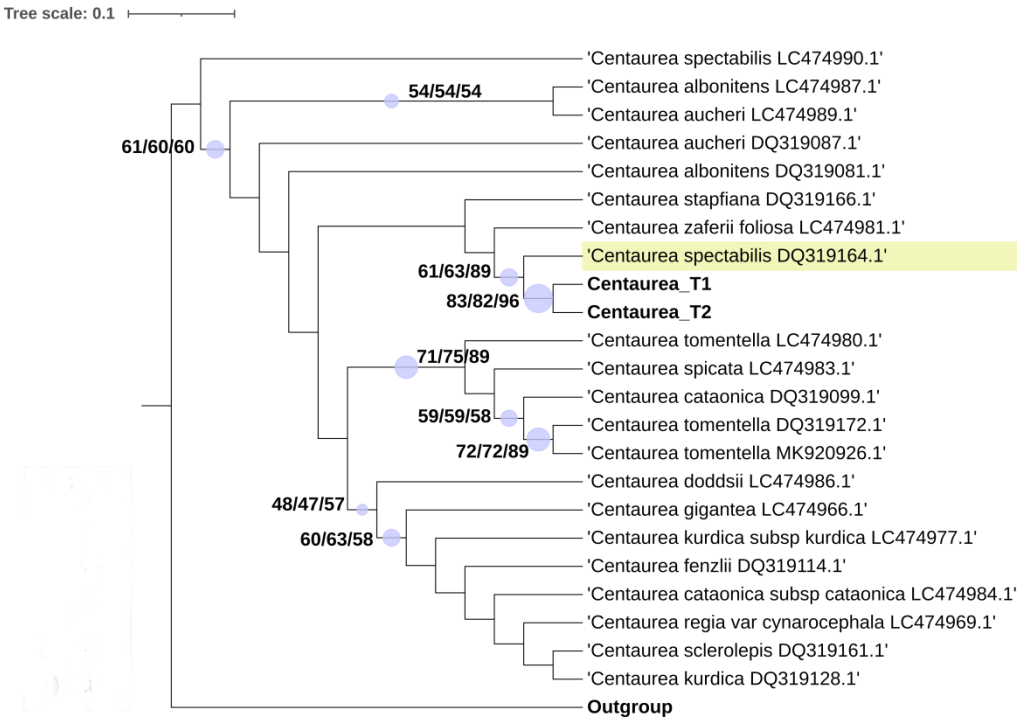

Figure 2. Phylogenetic tree of *Centaurea* species Türkiye, including two samples of *C. bingoelensis* (T1 and T2) analyzed in this study. Bootstrap support values are indicated by the size of the purple circles along the branches, with values ranging from 0.46 to 0.83. The tree was constructed based on ITS region sequences, and branch lengths represent genetic distance. Numbers along branches indicate confidence percentages in neighbor-joining (NJ-JC69), maximum likelihood (ML-TN93+G) and maximum parsimony (MP) analyses (Examples

identified in the study are marked in bold, branching points with Bootstraps values above 40% are shown with purple dots).

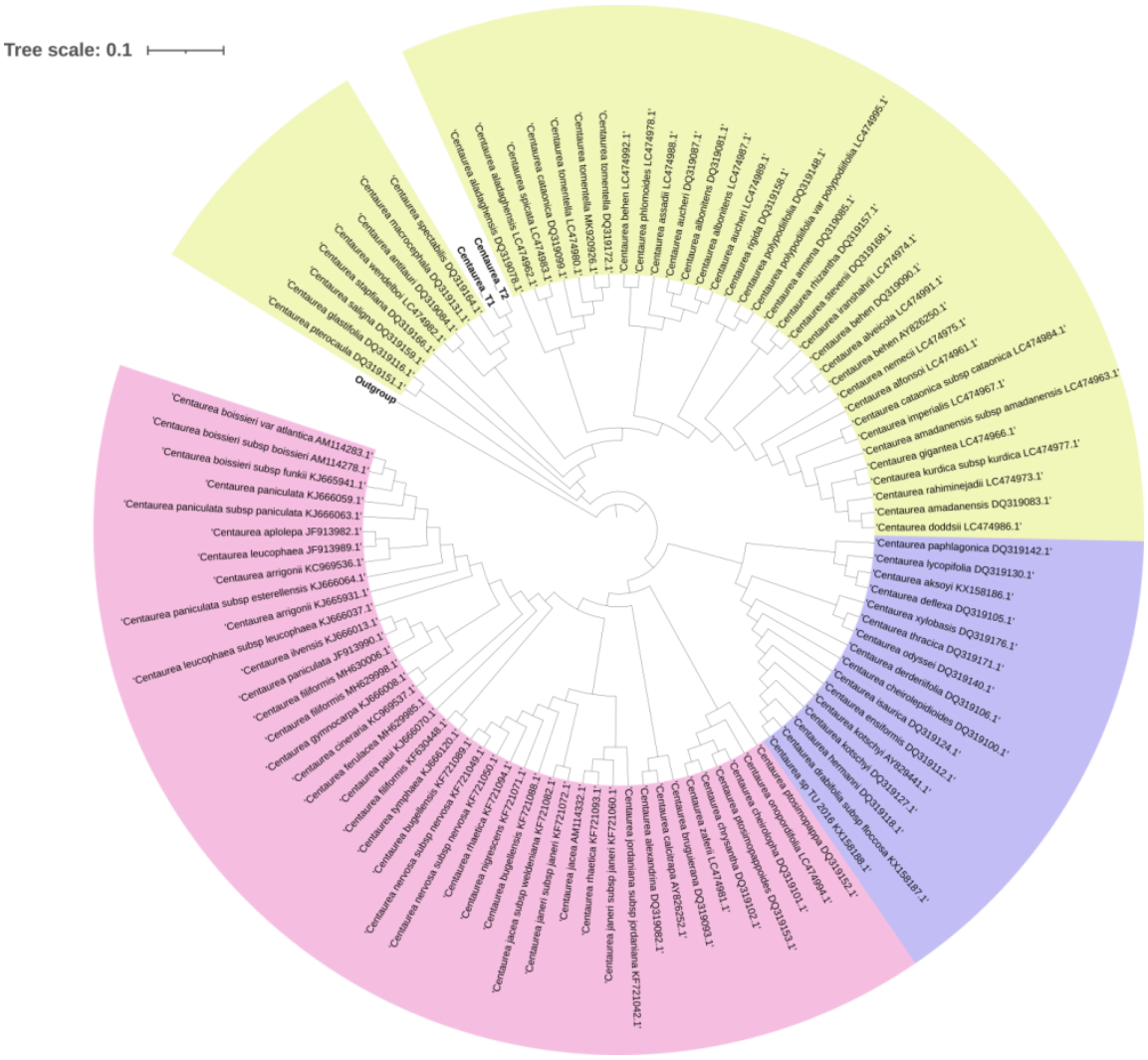

Figure 3. Phylogenetic relationships among identified Centaurea species distributed in Türkiye. The tree is based on ITS region sequences, and taxa are grouped by color to indicate major phylogenetic clades. Bootstrap values (from JC69, ML-TN93+G, and MP methods) were used to construct the consensus tree but are not displayed here.

In this study, phylogenetic analysis was performed by combining the DNA sequences obtained from the endemic species *C. bingoelensis* with the DNA sequences of other *Centaurea* species available in the NCBI database. Two ITS nucleotide sequences derived from two plant samples collected in the study area were used to assess interspecific and intraspecific variation, based on Maximum Likelihood (ML) analysis using the Tamura-Nei 1993 model with gamma distribution (TN93+G). Samples from different locations showed similar morphological features, and these results were consistent with DNA sequencing data. Furthermore, no genetic differences were observed in the ITS region among *C. bingoelensis* specimens collected from different sites Phylogenetic analysis revealed three major clades (Figure 3). A notable finding was that *C. bingoelensis*, which is morphologically similar to *C. fenzlii* and *C. obtusifolia,* clustered with *C. spectabilis,* supported by a high bootstrap value (89%) (Figure 2). However, *C. fenzlii* and *C. obtusifolia* could not be included in the phylogenetic comparison due to the absence of ITS data in NCBI database. With the advancement of phylogenomic approaches, numerous taxa previously misclassified have been reassigned, enabling a clearer understanding of species boundaries. These methods help distinguish between intraspecific variation, introgression, and true speciation, and allow for deeper taxonomic reassessment of evolutionary units, particularly in complex taxa such as *Centaurea* (Wagner et al., 2013; Baumsteiger et al., 2017).

All analyses generated slightly different tree topologies, differing only in poorly supported internal nodes. Therefore, only the Neighbor-Joining (NJ) tree is presented (Figure 2), while notable differences with other topologies are discussed where relevant. All topologies supported the close association among *Centaurea* species. This study represents the first phylogenetic analysis of *C. bingoelensis* that incorporates nearly all currently available ITS sequences of the genus *Centaurea*. Phylogenetic trees were rooted using *Astragalus mongholicus* (AF359750.1) as the outgroup. Despite low bootstrap and posterior probability values in some branches (Figure 3), the general tree topologies were consistent. Significant genetic variation was observed between *Centaurea* species and subspecies, confirming the need for a more comprehensive taxonomic revision. Phylogenetic relationships among European taxa also conformed to their geographic distribution, and ITS region was shown to be a reliable marker for taxonomic clarification. Nonetheless, a complete revision of *Centaurea* taxonomy and systematics will require broader sampling and more detailed morphological, karyological, and molecular analyses.

Both DNA sequence and morphological data revealed that the *C. bingoelensis* specimens analyzed in this study were closely related. This raises questions about their phylogenetic placement within the genus, especially in relation to phytogeographic lineages of *Centaurea*. Phylogenetic analysis using multiple methods, including Maximum Likelihood (under the Jukes-Cantor 1969 and Tamura-Nei 1993+G models) and Maximum Parsimony with1000 bootstrap replicates, consistently placed *C. bingoelensis* outside the clades formed by previously described species. These results support its recognition as a distinct taxon, as originally proposed by Behçet et al. (2017) (Figure 2). Interestingly, although *C. bingoelensis* is a narrow endemic, our results showed a relatively high level of genetic diversity in this species. This was supported by various statistical analyses based on NJ, ML, and MP methods, all indicating genetic variance among species (Saitou and Nei, 1987). According to genetic theory, narrowly endemic species are expected to have low genetic diversity due to small population sizes, population isolation, inbreeding, and ecological specialization (Babbel and Selander 1974; Frankham 2005; López-Pujol et al., 2016). Indeed, meta-analyses have shown a consistent association between endemism and low genetic variation (Nybom, 2004). However, our findings suggested that the ITS region can be a useful molecular marker in evaluating genetic diversity and resolving taxonomic complexity within the difficult genera such as *Centaurea*. Garcia-Jacas et al. (2006) reported that ITS-based phylogenies divided *Centaurea* into three main groups:(1) Mediterranean/European-Siberian, (2) Eastern Mediterranean, and (3) Eastern Mediterranean and Iran-Turanian. Consistent with this, C. bingoelensis clustered within Group 2, along with other *Centaurea* species native in Türkiye. This group is the largest lineages within *Centaurea*, comprising approximately 200 species distributed across the Caucasus, Greece, Iran, and Türkiye (Garcia-Jacas et al., 2006).

Furthermore, López-Pujol et al. (2016) noted a lack of correlation between morphological and genetic classification in *Centaurea* due to the high allopatric (speciation) diversity of genus. Our findings support this, as *C. bingoelensis*, while morphologically similar to *C. obtusifolia* and *C. fenzlii*, clustered phylogenetically with *C. spectabilis*. In terms of geographic distribution, *C. bingoelensis* occurs in an area that overlaps with the ranges of *C. obtusifolia* (South), *C. spectabilis* and *C. fenzlii* (East). Based on phylogenetic relationships, it is likely that *C. bingoelensis* originated from Eastern Anatolia rather than Southeastern Anatolia.

CONCLUSION

This study provides the first molecular phylogenetic assessment of the narrowly endemic species *C. bingoelensis* based on ITS region sequences. The results reveal that *C. bingoelensis*, despite its morphological similarity to *C. spectabilis* and *C. fenzlii.* No significant genetic variation was observed between individuals of *C. bingoelensis* from different collection sites, supporting its status as a genetically coherent species. These findings underscore the importance of integrating molecular data into taxonomic studies, particularly for morphologically complex and geographically overlapping taxa. A broader phylogenetic and morphological reassessment is recommended to fully resolve the evolutionary relationships within the genus *Centaurea.*

DNA availability

The ITS sequences generated in this study, ITS1-5.8S-ITS2, have been deposited in GenBank under the accession numbers OM905073.1 and OM905074.1. Reference sequences used for phylogenetic analysis, along with their GenBank accession numbers and original sources, are listed in Supplementary Table 1.

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Declaration of interests
The authors of this article declare that there are no conflicts of interest.

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The authors declare that they have contributed equally to this article.

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Supplementary Material

The GENBANK accession numbers are given in table.

Taxa	Ac. No
C. aksoyi	KX158186.1
C. aladaghensis	DQ319078.1, LC474962.1
C. albonitens	DQ319081.1, LC474987.1
C. alexandrina	DQ319082.1
C. alfonsoi	LC474961.1
C. alveicola	LC474991.1
C. amadanensis	DQ319083.1, LC474963.1
C. antitauri	DQ319084.1
C. aplolepa	JF913982.1
C. armena	DQ319085.1
C. arrigonii	KC969536.1, KJ665931.1
C. assadii	LC474988.1
C. aucheri	DQ319087.1, LC474989.1
C. behen	AY826250.1, DQ319090.1, LC474992.1
C. boissieri* subsp. *boissieri	AM114278.1
C. boissieri* subsp. *funkii	KJ665941.1
C. boissieri* var. *atlantica	AM114283.1
C. bruguierana	DQ319093.1
C. bugellensis	KF721088.1, KF721089.1
C. calcitrapa	AY826252.1
C. cataonica	DQ319099.1, LC474984.1
C. cheirolepidioides	DQ319100.1
C. cheirolopha	DQ319101.1
C. chrysantha	DQ319102.1
C. cineraria	KC969537.1
C. deflexa	DQ319105.1
C. derderiifolia	DQ319106.1

C. doddsii	LC474986.1
C. drabifolia* subsp. *floccosa	KX158187.1
C. ensiformis	DQ319112.1
C. ferulacea	MH629985.1
C. filiformis	KF630448.1, MH629998.1, MH630006.1
C. gigantea	LC474966.1
C. glastifolia	DQ319116.1
C. gymnocarpa	KJ666008.1
C. hermanni	DQ319118.1
C. ilvensis	KJ666013.1
C. imperialis	LC474967.1
C. iranshahrii	LC474974.1
C. isaurica	DQ319124.1
C. jacea	AM114332.1
C. jacea* subsp. *weldeniana	KF721082.1
C. janeri* subsp. *janeri	KF721060.1, KF721072.1
C. jordaniana* subsp. *jordaniana	KF721042.1
C. kotschyi	AY829441.1, DQ319127.1
C. kurdica* subsp. *kurdica	LC474977.1
C. leucophaea	JF913989.1
C. leucophaea* subsp. *leucophaea	KJ666037.1
C. lycopifolia	DQ319130.1
C. macrocephala	DQ319131.1
C. nemecii	LC474975.1
C. nervosa* subsp. *nervosa	KF721049.1, KF721050.1
C. nigrescens	KF721071.1
C. odyssei	DQ319140.1
C. onopordifolia	LC474994.1
C. paniculata	JF913990.1, KJ666059.1
C. paniculata* subsp. *esterellensis	KJ666064.1
C. paniculata* subsp. *paniculata	KJ666063.1
C. paphlagonica	DQ319142.1
C. paui	KJ666070.1
C. phlomoides	LC474978.1
C. polypodiifolia	DQ319148.1
C. polypodiifolia* var. *polypodiifolia	LC474995.1
C. pterocaula	DQ319151.1
C. ptosimopappa	DQ319152.1
C. ptosimopappoides	DQ319153.1
C. rahiminejadii	LC474973.1
C. rhaetica	KF721093.1, KF721094.1
C. rhizantha	DQ319157.1
C. rigida	DQ319158.1
C. saligna	DQ319159.1
C. spectabilis	DQ319164.1
C. spicata	LC474983.1
C. stapfiana	DQ319166.1
C. stevenii	DQ319168.1
C. thracica	DQ319171.1
C. tomentella	DQ319172.1, LC474980.1, MK920926.1
C. tymphaea	KJ666120.1
C. wendelboi	LC474982.1
C. xylobasis	DQ319176.1
C. zaferii	LC474981.1
Outgroup	
Astragalus mongholicus	AF359750.1

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Original Article

Molecular characterization of some peach and nectarine hybrids by ISSR and SSR markers

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ABSTRACT

The *Prunus* genus includes valuable fruit trees such as cherries, almonds, apricots, plums, peaches, and nectarines. Peaches and nectarines are among the most widely cultivated fruits globally and can adapt to temperate and subtropical climate conditions. In this study, the genetic relationships of 96 peach and nectarine hybrids were analyzed using Simple Sequence Repeat (SSR) and Simple Intersequence Repeat (ISSR) markers. These genotypes consist of hybrid VxÜ (Venüs x Üstün) and RxÜ (Stark Red Gold x Üstün) obtained through the hybridization of peach and nectarine varieties. 5 SSR and 14 ISSR primers were used for both VxÜ and RxÜ genotypes. In the SSR analysis of hybrid VxÜ and RxÜ genotypes, 12 bands were obtained, all polymorphic, resulting in a polymorphism rate of 100%. The band size ranged from 150 to 240 bp. The PIC values ranged from 0.32 to 0.91, with an average of 0.62. In the ISSR analysis of hybrid RxÜ and VxÜ genotypes, 163 bands were obtained, of which 150 were polymorphic and polymorphism rate of 91%. The band size range varied between 300 and 2000 bp. Genetic similarity values among genotypes were calculated, and a UPGMA cluster analysis was performed to create a dendrogram. The data and dendrograms obtained from genetic analysis were compared. The dendrograms generated from the SSR and ISSR analyses were divided into two main clusters. In the dendrogram based on SSR analysis, the VÜ-103 hybrid formed a distinct group, separate from all other genotypes. Conversely, in the dendrogram derived from ISSR analysis, the VÜ hybrids clustered within the first main branch, while the RU hybrids were grouped within the second main branch. The results of the study showed that both SSR and ISSR markers are potential tools for determining genetic diversities and genetic relationships of *Prunus* hybrids and can be used in breeding programs.

Key words: Peach, Nectarine, Molecular Characterization, SSR, ISSR

Bazı şeftali ve nektarin melezlerinin ISSR ve SSR belirteçleri ile moleküler karakterizasyonu

ÖZ

Prunus cinsi kiraz, badem, kayısı, erik, şeftali ve nektarin gibi değerli meyve ağaçlarını içerir. Şeftali ve nektarinler dünyada en yaygın yetiştirilen meyveler arasındadır ve ılıman ve subtropikal iklim koşullarına uyum sağlayabilir. Bu çalışmada, 96 şeftali ve nektarin melezinin genetik ilişkileri Basit Dizi Tekrarı (SSR) ve Basit Diziler Arası Tekrar (ISSR) markırları kullanılarak analiz edilmiştir. Bu genotipler şeftali ve nektarin çeşitlerinin melezlenmesiyle elde edilen hibrit VxÜ (Venüs x Üstün) ve RxÜ'den (Stark Red Gold x Üstün) oluşmaktadır. Hem VxÜ hem de RxÜ genotipleri için 5 SSR ve 14 ISSR primeri kullanılmıştır. Hibrit VxÜ ve RxÜ genotiplerinin SSR analizinde, hepsi polimorfik olan 12 bant elde edilmiş ve %100 polimorfizm oranı elde edilmiştir. Bant büyüklüğü 150 ila 240 bp arasında değişmiştir. PIC değerleri 0,32 ila 0,91 arasında değişmiş, ortalama 0,62 olarak belirlenmiştir. Hibrit RxÜ ve VxÜ genotiplerinin ISSR analizinde 163 bant elde edilmiş, bunların 150'si polimorfik olarak belirlenmiş ve polimorfizm oranı %91 olarak saptanmıştır. Bant büyüklüğü 300 ile 2000 bp arasında değişmiştir. Genotipler arasındaki genetik benzerlik değerleri hesaplanmış ve bir dendrogram

oluşturmak için bir UPGMA kümeleme analizi yapılmıştır. Genetik analizden elde edilen veriler ve dendrogramlar karşılaştırılmıştır. SSR ve ISSR analizleri sonucunda elde edilen dendrogramlar 2 ana kola ayrılmıştır. SSR analizleri ile elde edilen dendrogramda VÜ-103 genotipi diğer tüm genotiplerden ayrı grupta yer almıştır. ISSR analizleri ile elde edilen dendrogramda 1. ana kolda VÜ genotipleri, 2. ana kolda ise RÜ genotipleri kümelenmiştir. Çalışmanın sonuçları, hem SSR hem de ISSR belirteçlerinin Prunus melezlerinin genetik çeşitliliğini ve genetik ilişkilerini belirlemek için potansiyel araçlar olduğunu ve ıslah programlarında kullanılabileceğini göstermiştir.

Anahtar kelimeler: Şeftali, Nektarin, Moleküler Karakterizasyon, SSR, ISSR.

INTRODUCTION

Peach (*Prunus persica*) is a highly nutritious and valuable fruit, recognized for its significant food and nutritional benefits. Both peach and nectarine are essential today for their culinary applications and ornamental purposes. The high economic value of peach is of considerable commercial significance. Considering these factors, research on peach and nectarine in fruit breeding has become increasingly vital (Eroğlu and Mısırlı, 2012). Peach-growing regions are typically located in temperate and subtropical climates, between latitudes of 30° and 45°. Countries such as China, Spain, Turkey, Greece, Iran, the USA, Egypt, Chile, and India are prominent producers. The origin of peach is widely accepted to be Iran (Persia). Historical records from China suggest that peaches spread from China to Iran and subsequently to Europe (LaRue, 1989; Dosba, 2003; Okie et al., 2008). Peaches are classified into three distinct forms: Hairy peaches (*P. persica vulgaris* Mill.), Hairless peaches (nectarines) (*P. persica* var. *nectarina* Maxim.), and Tomato peaches (*P. persica* var. *platycarpa*). Nectarines are a botanical variety of peaches; however, they are distinguished by their hairless fruit skin, which is caused by the expression of a recessive gene within nectarine genetics (Yüce, 2018). Like peaches, nectarines are grown in temperate climates. The diploid chromosomal structure of both peaches and nectarines offers advantages for breeding studies and new variety development, though it also presents certain susceptibilities.

The phenolic compounds found in peaches contribute significantly to their sensory appeal and flavor, but they also play a role in the potential browning of the fruit during its development (Kaynaş et al., 2022). In plant breeding, it is essential to investigate parameters such as genome mapping, phylogenetic analysis, gene tagging, genetic diversity, and interspecific relationships, as they are critical for understanding species diversity. Through breeding efforts, nectarines have been developed with a hairless trait, similar nutritional value to peaches, and considerable commercial value.

Considering the broader context of plant breeding, including the economic development of our country, the conservation of our cultural heritage, and the enhancement of genome libraries used in fruit breeding, the significance of plant breeding studies becomes apparent. Developing new plant varieties through breeding is crucial for food diversity, human health, and the well-being of organisms that rely on plants for nutrition, ultimately contributing to maintaining ecological balance (Yu et al., 2021). Today, molecular markers have significantly reduced the time and effort required in plant breeding studies. The application of molecular markers in fruit cultivation plays a pivotal role in clarifying genetic references, enabling more accurate, efficient, and informed breeding processes while safeguarding these genetic resources (Filiz and Koç, 2011).

Molecular markers can be broadly categorized into two groups: PCR-based marker systems and non-PCR-based marker systems. RFLP (Restriction Fragment Length Polymorphism) is an example of a non-PCR-based marker technique. PCR-based molecular markers include AFLP (Amplified Fragment Length Polymorphism), RAPD (Random Amplified Polymorphic DNA), VNTR (Variable Number of Tandem Repeats), CAPS (Cleaved Amplified Polymorphic Sequences), organelle microsatellites (e.g., chloroplast DNA), SRAP (Sequence-Related Amplified Polymorphism), TRAP (Tartrate-Resistant Acid Phosphatase), and EST (Expressed Sequence Tag) marker technologies. Additionally, SSR (Simple Sequence Repeat) and ISSR (Inter-Simple Sequence Repeat) marker techniques are frequently employed in plant breeding research (Domblides and Domblides, 2023; Yang et al., 2023; Schulman, 2007; Sang et al., 2021; Güleç et al., 2010). Molecular marker techniques are crucial tools for identifying genetic differences at the DNA sequence level.

Microsatellites, also known as simple sequence repeats (SSRs), consist of repeated motifs of 1 to 6 nucleotides. The gene sequences flanking these microsatellite regions are inherited in a stable, non-variable manner between individuals of different species, allowing for the determination of species diversity (Aka Kaçar, 2004). This feature makes SSR markers particularly advantageous in various scientific studies, such as genetic mapping, gene tagging, and interspecies characterization. SSR markers offer several benefits, including requiring minimal DNA amounts, being codominant and stable, being widely distributed throughout the

genome, having high polymorphism, and being suitable for automation and high-throughput analysis (Powell et al., 1996). ISSR (Inter-Simple Sequence Repeat) markers amplify the DNA region between two microsatellites using primers that are specific and structurally unique (e.g., double, triple, quadruple, quintuple repeats). The ISSR marker is a dominant marker, and a significant advantage is its ability to specifically amplify the DNA region between two microsatellites without the need for sequence information. ISSR markers are widely used in research on gene mapping, genetic characterization, and the assessment of genetic similarity (Yorgancılar et al., 2015). This study aimed to determine the molecular characterization and genetic relationships of peach and nectarine varieties and their hybrids developed during the breeding process using SSR and ISSR markers.

MATERIALS AND METHODS

Plant Materials

In this study, the Üstün peach variety, Venüs nectarine variety, Stark Red Gold nectarine variety, and their hybrids, all belonging to the P. persica species within the Rosaceae family, were utilized. The Üstün peach variety is a J.H. Hale-type peach obtained through a bud mutation. It has a late ripening period, typically observed at altitudes between 1400 and 1500 meters. The fruit exhibits a distinctly hairy skin with red cheeks on a yellow background. The fruit stem is shorter compared to other peach varieties. The flesh is firm and yellow, and the flavor profile is notably pleasant. The flesh of the Venüs nectarine variety is yellow, and the fruit ripens late. It is a pomologically significant variety with promising traits for breeding, including its taste, fruit size, and color. Its ripening period is approximately 10 days later than that of the Stark Red Gold nectarine variety. The Stark Red Gold nectarine variety, characterized by yellow flesh, is distinguished by its late ripening, larger size, and flavor, which align with the traits of the Venüs nectarine variety. It ripens about 10 days earlier than the Venüs nectarine variety (Çömlekçioğlu, 2014). The RÜ hybrid genotypes exhibit a later flowering time. Genotypes with higher fruit weight have been observed. Furthermore, the body diameter of RÜ hybrids was found to be thicker compared to VÜ hybrids. Specifically, the body of the RÜ8 genotype was measured at 108.12 mm. Upon examination of the genotypes, it was observed that the hairier genotypes were predominantly present in the RÜ hybrid group. A significant number of nectarine genotypes were produced in the VÜ hybrids. VÜ hybrids have a shorter harvest period compared to RÜ hybrids. Additionally, it was noted that the flesh of nectarines derived from VÜ hybrids is typically white or yellow (Çömlekçioğlu, 2014). The variety and hybrid genotypes utilized in this study are presented in Table 1. A total of 96 genotypes, consisting of 48 RÜ and 48 VÜ hybrids, were employed for the analysis. These hybrids were developed through research conducted as part of peach and nectarine breeding programs at the Department of Horticulture, Faculty of Agriculture, Çukurova University.

Table 1. Varieties and hybrids used in this study

No	Genotype	No	Genotype	No	Genotype	No	Genotype
1	Stark Red Gold	**25**	RÜ- 43	**1**	Venüs	**25**	VÜ-86
2	Üstün	**26**	RÜ- 46	**2**	Üstün	**26**	VÜ-88
3	RÜ- 2	**27**	RÜ- 47	**3**	VÜ-1	**27**	VÜ-89
4	RÜ- 4	**28**	RÜ- 53	**4**	VÜ-6	**28**	VÜ-91
5	RÜ- 5	**29**	RÜ- 61	**5**	VÜ-13	**29**	VÜ-92
6	RÜ- 6	**30**	RÜ- 65	**6**	VÜ-15	**30**	VÜ-96
7	RÜ- 8	**31**	RÜ- 69	**7**	VÜ-24	**31**	VÜ-100
8	RÜ- 10	**32**	RÜ- 71	**8**	VÜ-34	**32**	VÜ-101
9	RÜ- 11	**33**	RÜ- 73	**9**	VÜ-41	**33**	VÜ-102
10	RÜ- 12	**34**	RÜ- 76	**10**	VÜ-65	**34**	VÜ-103
11	RÜ- 13	**35**	RÜ- 78	**11**	VÜ-70	**35**	VÜ-104
12	RÜ- 16	**36**	RÜ- 80	**12**	VÜ-71	**36**	VÜ-107
13	RÜ- 17	**37**	RÜ- 81	**13**	VÜ-73	**37**	VÜ-109
14	RÜ- 18	**38**	RÜ- 84	**14**	VÜ-74	**38**	VÜ-110
15	RÜ- 19	**39**	RÜ- 85	**15**	VÜ-75	**39**	VÜ-111
16	RÜ- 22	**40**	RÜ- 87	**16**	VÜ-76	**40**	VÜ-112
17	RÜ- 23	**41**	RÜ- 88	**17**	VÜ-77	**41**	VÜ-113
18	RÜ- 24	**42**	RÜ- 90	**18**	VÜ-78	**42**	VÜ-114
19	RÜ- 31	**43**	RÜ- 92	**19**	VÜ-79	**43**	VÜ-115
20	RÜ- 33	**44**	RÜ- 93	**20**	VÜ-80	**44**	VÜ-116
21	RÜ- 34	**45**	RÜ- 95	**21**	VÜ-81	**45**	VÜ-117
22	RÜ- 36	**46**	RÜ-101	**22**	VÜ-82	**46**	VÜ-118
23	RÜ- 40	**47**	RÜ-104	**23**	VÜ-83	**47**	VÜ-119
24	RÜ- 41	**48**	RÜ-109	**24**	VÜ-85	**48**	VÜ-120

Methods

DNA Isolation and PCR Amplification Protocols

In this study, young leaves from cultivars and hybrids were utilized for DNA isolation. The leaves were washed thoroughly with distilled water, wrapped in aluminum foil, rapidly frozen in liquid nitrogen (-196°C), and subsequently stored at -80°C. DNA extraction was performed using the CTAB method as described by (Edwards et al., 1991). DNA concentration was measured using a NanoDrop ND 100 spectrophotometer (NanoDrop Technologies) and gel electrophoresis (Aka Kaçar et al., 2014).

SSR Analysis

PCR reactions were performed using five synthetically designed SSR primers specific to Prunus species, have high levels of polymorphism, as described by Aka Kaçar et al. (2005) (Table 2). Each reaction was prepared in a total volume of 20 µL, with the following components and their concentrations: ddH_2O: 5.00 µL, PCR Master Mix (2X): 8.00 µL, $MgCl_2$: 0.50 µL, M13 primer (Forward & Reverse): 0.50 µL, F + R primer: 1.00 µL, Template DNA (5 ng): 5.00 µL, Taq DNA polymerase: 0.05 µL. The amplifications were carried out using a Veriti thermal cycler (Applied Biosystems) under the following conditions: Initial denaturation: 95 ˚C for 5 min, 35 cycles of denaturation: 95 ˚C for 1 min, annealing: 55 ˚C for 30 sec, extension: 72 ˚C for 1 min, and final extension: 72 ˚C for 6 min.

Polyacrylamide Gel Preparation for Li-Cor Analysis

6.5% polyacrylamide gels were prepared for Li-Cor gel electrophoresis. The gel composition was as follows: Urea: 8.4 g, 50% long ranger acrylamide: 2.4 mL, 10X TBE buffer: 2.0 mL, TEMED: 15 µL, ammonium persulfate (APS, 10%): 150 µL. The operating parameters for preheating were set to 1000 V, 35 mA, and 25 W at 45°C for 25 minutes. After adding formamide loading buffer, the samples were denatured at 95°C for 4 minutes, and 1 µL was loaded onto the gel. Electrophoresis was conducted under the following conditions: 1500 V, 35 mA, and 50 W at 48°C for 1.5 hours.

Table 2. SSR primers used in the study

No	Primer code	Sequence	
1	BPPCT009	F:ATTCGGGTCGAACTCCCT	R:ACGAGCACTAGAATAACCCTCTC
2	MA014	F:CCATGAACCCGGAGAGAGAA	R:CAACACGTGTCATCCGTTCG
3	BBCT012	F:ACTTCCATTGTCAGGCATCA	R:GGAGCAACGATGGAGTGC
4	BBCT008	F:ATGGTGTGTATGGACATGATGA	R:CCTCAACCTAAGACACCTTCACT
5	BBCT004	F:CTGAGTGATCCATTTGCAGG	R:AGGGCATCTAGACCTCATTGTT

ISSR Analysis

PCR reactions were conducted using 14 synthetically designed ISSR primers. These primers were selected based on their demonstration of 100% polymorphism in a study by (Genişel 2013). Details of the primers used in this study are presented in Table 3.

Table 3. ISSR primers used in the study

No	**Primer Code**	**Sequance (5’-3’)**
1	UBC 807	AGA GAG AGA GAG AGA GT
2	UBC 808	AGA GAG AGA GAG AGA GC
3	UBC 810	GAG AGA GAG AGA GAG AT
4	UBC 811	GAG AGA GAG AGA GAG AC
5	UBC 812	GAG AGA GAG AGA GAG AC
6	UBC 815	CTC TCT CTC TCT CTC TG
7	UBC 816	CAC ACA CAC ACA CAC AT
8	UBC 818	CAC ACA CAC ACA CAC AG
9	UBC 820	GTG TGT GTG TGT GTG TC
10	UBC 827	ACA CAC ACA CAC ACA CG
11	UBC 834	AGA GAG AGA GAG AGA GT
12	UBC 835	AGA GAG AGA GAG AGA GC
13	UBC 845	CTC TCT CTC TCT CTC TG
14	UBC 850	GTG TGT GTG TGT GTG TC

ISSR-PCR analyses were performed in a volume of 25 ul mixing with 10 ng of RÜ and VÜ DNA template, 2X PCR Mastermix (Fermentas K0171, Waltham, MA, USA), 25 mM $MgCl_2$, 10 µM primer, and 1 U of Taq DNA polymerase (Fermentas EP0402). PCR amplifications were carried out in a Veriti thermal cycler (Applied Biosystems) using the following program: initial denaturation for 3 min at 95 C; 35 cycles of 45 sec at 95 ˚C, 1 min at 55 ˚C, and 45 sec at 72 ˚C; and a final 7 min of elongation at 72 ˚C. Reactions were then held at 4 ˚C.

Agarose gel electrophoresis

The amplified products were separated on 1.5% agarose gel electrophoresis. Agarose gel electrophoresis was conducted in 0.5 X TAE buffer at 80V and 100 mA for 3.5 h. The gels were stained with ethidium bromide and DNA bands were observed on UV-transilluminator and photographed by a gel documentation system (VersaDoc/BioRad). A 1 kb DNA ladder (Fermentas) was used to determine the fragment size.

Data Analysis for SSR and ISSR Markers

SSR and ISSR data were recorded in a binary format, with the presence of a band denoted as "1" and its absence as "0". Only reproducible bands were scored across all tested genotypes. Genetic relationships among RÜ and VÜ genotypes were assessed using the unweighted pair-group method with arithmetic mean (UPGMA) cluster analysis via the PAST software package (Hammer et al. 2001. Bootstrap values for the clusters were calculated based on 1,000 replicates. The representativeness of the dendrograms was evaluated by calculating the cophenetic correlation coefficient, r, using Mantel's matrix correspondence test (Mantel, 1967). This test compares the cophenetic matrix derived from the dendrogram with the original similarity matrix, measuring how accurately the dendrogram reflects the similarity data. Cophenetic correlation coefficient supports the robustness and interpretability of the clustering results, which is essential for drawing meaningful conclusions in genetic studies. Cophenetic correlation coefficient value close to 1.0 indicates a high degree of fidelity between the dendrogram and the original data, suggesting that the clustering pattern reliably represents the underlying genetic relationships. In addition to UPGMA analysis, principal coordinate analysis (PCoA) was performed to detect genetic associations among the genotypes. A similarity matrix was constructed using Jaccard coefficients and subsequently used for PCoA. The primers' polymorphism information content (PIC) was calculated as (Smith et al., 1997) described the following formula, providing a measure of the discriminatory power of the primers used.

$$PIC = \sum^{n} f_i^2 i = 1$$

RESULTS AND DISCUSSION

The genetic relationships of 48 Stark Red Gold x Üstün (RÜ) and 48 Venüs x Üstün (VÜ) genotypes obtained by crossing Stark Red Gold (nectarine), Venüs (nectarine) and Üstün (peach) varieties were investigated using SSR and ISSR markers.

DNA Isolation

The success of DNA isolation is determined by the quantity, quality, and usability of the extracted DNA (Şimşek et al., 2008). DNA quality is commonly evaluated using the A260/A280 purity ratio. High-quality DNA samples typically exhibit a ratio between 1.8 and 2.0. A ratio exceeding 2.0 may indicate contamination by substances such as RNA, chloroform, or phenol, whereas a ratio below 1.6 suggests the presence of proteins or phenolic compounds (Hoisington et al. 1992; Şimşek et al. 2008). In this study, A260/A280 ratios measured using a Nanodrop spectrophotometer following DNA isolation ranged from 1.72 (VÜ82) to 2.23 (VÜ15) in hybrid VÜ genotypes. Similarly, the ratios for hybrid RÜ genotypes varied between 1.55 (RÜ22) and 2.32 (RÜ87).

SSR Analyses and Polymorphism Assessment

In SSR analyses, 5 primers were used. As a result of the band scoring, the total number of bands (number), band length intervals (bp), and polymorphism rate (%) were calculated. The band profile table obtained as a result of the SSR analysis is presented in Table 4.

Table 4. The band profile table obtained as a result of the SSR analysis

Number of Primers	Primers	Total Number of Bands (Number)	Number of Polymorphic Bands (Number)	Band Length Intervals (bp)	Polymorphism Rate (%)	PIC (%)
1	BPPCT009	3	3	190-200	100	0,91
2	MA014	3	3	165-185	100	0,33
3	BBCT012	1	1	240	100	0,32
4	BBCT008	2	2	150-165	100	0,68
5	BBCT004	3	3	165-185	100	0,85
TOTAL	**5**	**12**	**12**	**150-240**	**100**	**0,62**

Examination of the band profile revealed 12 polymorphic bands, resulting in a 100% polymorphism rate. The band size ranged from 150 to 240 bp, indicating the high discriminatory power of the analyzed SSR markers. The PIC values ranged from 0.32 to 0.91, with an average of 0.62. (Wünsch, 2009) studied SSR markers across 10 different Prunus species, reporting a band size range of 179–272 bp. (Kumar et al., 2023) reported PIC values ranging from 0.317 to 0.836, with an average of 0.563, in their analysis of 41 peach genotypes. PIC values provide critical information about the degree of polymorphism among genotypes, with higher values indicating greater genetic diversity. The relatively high average PIC value observed in this study underscores the effectiveness of SSR markers in revealing genetic differences among the genotypes. When comparing the PIC values and SSR marker results with the literature, this study's findings align with those reported in previous molecular characterization studies, contributing valuable data to the existing body of knowledge.

Genetic Similarity Analysis Based on SSR Markers

The dendrogram shown in Figure 1 was obtained from the SSR marker analysis. The genetic similarity coefficients for the parent varieties were as follows: the genetic similarity coefficient between the Stark Red Gold variety and the Üstün variety was 0.55, while the genetic similarity coefficient between the Venüs variety and the Üstün variety was 0.50. The genetic similarity coefficient between the Stark Red Gold and Venüs varieties was 0.75. The genotype most closely related to the Üstün variety is the VÜ82 genotype, with a genetic similarity coefficient of 0.73. In contrast, the genotypes with the most distant genetic similarity to Üstün are RÜ11, RÜ13, RÜ71, RÜ80, RÜ81, and VÜ107, all showing a genetic similarity coefficient of 0.22. Regarding the Venüs variety, the genotype with the closest genetic similarity is VÜ113, with a genetic similarity coefficient of 1.00, indicating complete similarity. The genotypes with the most distant genetic similarity to Venüs are VÜ112, VÜ103, VÜ86, RÜ22, and RÜ19, all with a genetic similarity coefficient of 0.29. For the Stark Red Gold variety, the genotype with the closest genetic similarity is VÜ24, also showing 100% similarity with a genetic similarity coefficient 1.00. The genotypes with the most distant genetic similarity to Stark Red Gold are RÜ22, VÜ86, VÜ103, and VÜ112, with a genetic similarity coefficient of 0.22. Genetic similarity coefficients among the genotypes ranged from 0.10 to 1.00. The most distant genotypes, with a genetic similarity coefficient of 0.10, were RÜ74 and VÜ6.

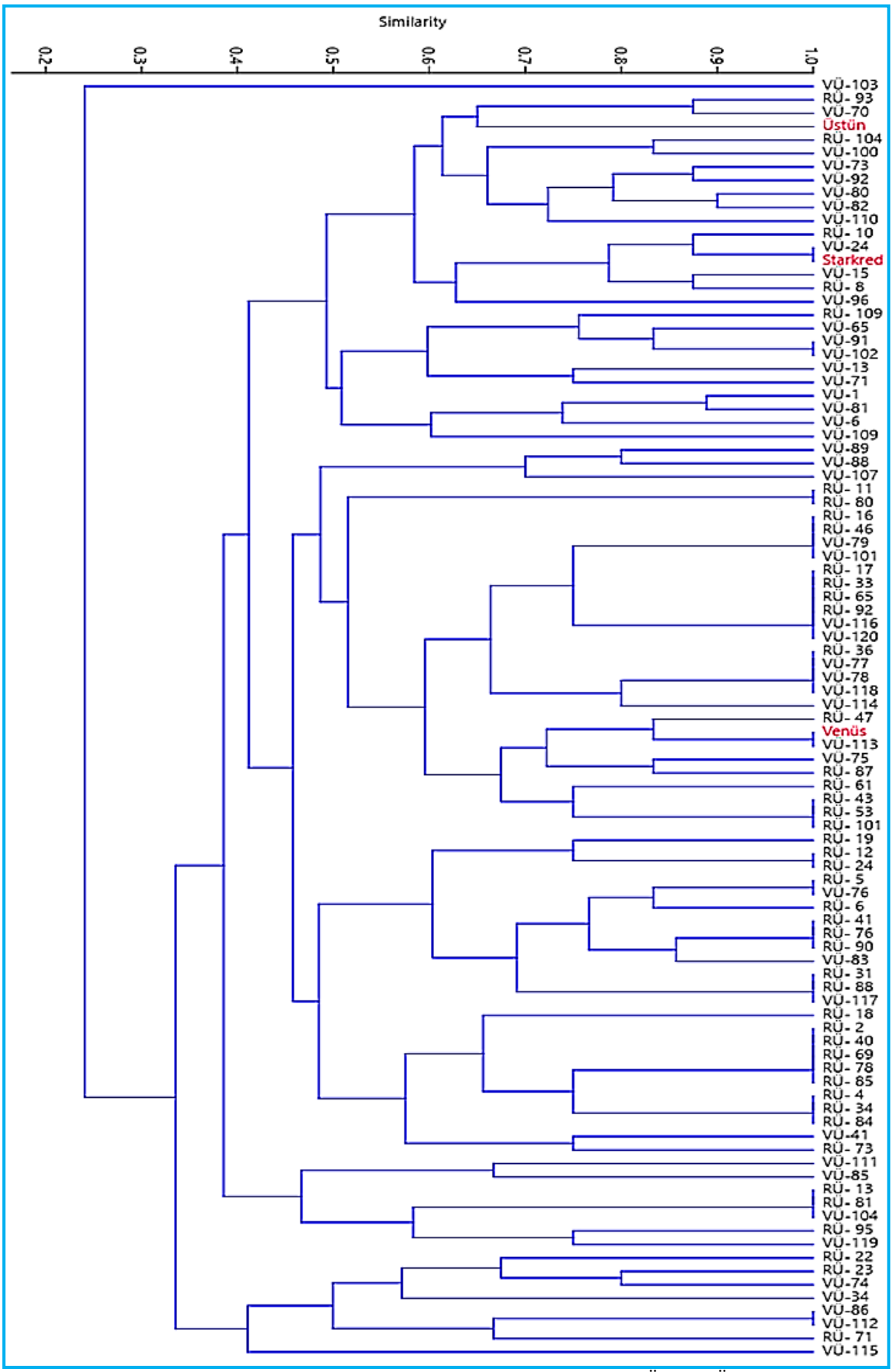

Figure 1. Dendrogram generated using UPGMA, showing relationships between RÜ and VÜ hibrids, using SSR data.

The PCoA analysis graph, presented in Figure 2, was generated based on SSR data. The hybrid RÜ and VÜ genotypes were observed to be distributed homogeneously across both the negative and positive regions of the coordinate. This two-dimensional graph explained 15% of the total molecular variation between genotypes in the first dimension, while the second dimension accounted for 17% of the total molecular variation.

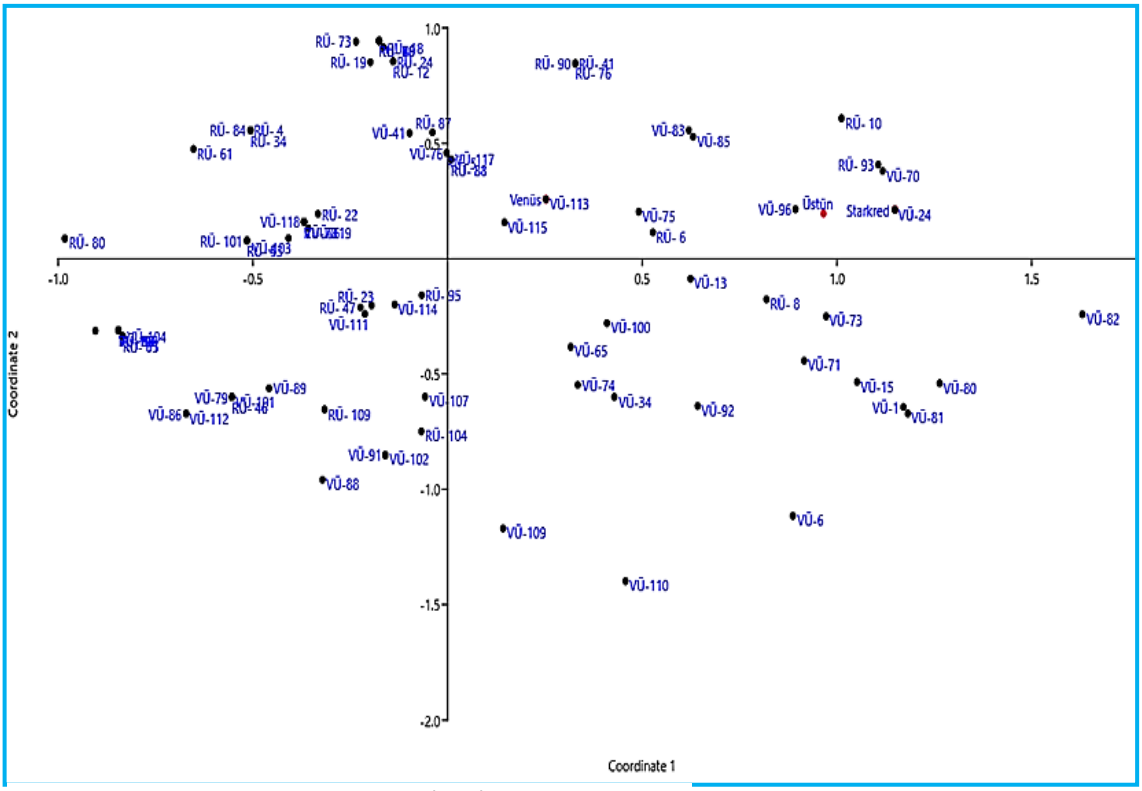

Figure 2. Principle Coordinate Analysis (PCo) based on SSR data

ISSR Analysis and Polymorphism Assessment

Fourteen ISSR primers were used in this study. The band profile table obtained as a result of the ISSR analysis is presented in Table 5.

Table 5. The band profile table obtained as a result of ISSR analysis

No	Primers Code	Total Number of Bands (Number)	Number of Polymorphic Bands (Number)	Band Length Intervals (bp)	Polymorphism Rate (%)	PIC (%)
1	UBC 807	13	13	300 - 1400	100	0,35
2	UBC808	13	8	300 - 1500	61	0,30
3	UBC810	16	16	300 - 1400	100	0,54
4	UBC811	15	15	300 - 2000	100	0,82
5	UBC 812	10	9	300 - 1400	90	0,43
6	UBC815	10	10	500-1500	100	0,81
7	UBC816	13	9	350 - 1700	69	0,75
8	UBC818	13	13	300 - 1650	100	0,76
9	UBC820	6	5	900 - 1700	83	0,74
10	UBC827	8	8	400 - 1300	100	0,75
11	UBC834	20	20	300 - 1000	100	0,86
12	UBC835	10	10	300 - 1300	100	0,38
13	UBC845	8	8	300 - 1200	100	0,73
14	UBC850	8	6	1000 - 2000	75	0,84
TOTAL	**14**	**163**	**150**	**300 - 2000**	**91**	**0,65**

A total of 9 primers out of the 14 primers analyzed showed 100% polymorphism. Primers showing 100% polymorphism were UBC807, UBC810, UBC811, UBC815, UBC818, UBC827, UBC834, UBC835, UBC845. 14 specific ISSR primers produced 163 bands, 150 of which were polymorphic, resulting in a polymorphism rate of 91%. The total number of bands obtained per primer varied between 6-20 (average 13 bands/primer), and the total number of polymorphic bands varied between 5-20 (average 12.5 bands/primer). The total polymorphism rate was calculated as 90%. The band size range varied between 300 and 2000 bp. Li et al. (2023) performed a genetic characterization study on 39 peach genotypes using ISSR and SRAP markers. Their study included 18 ISSR primers, four of which (UBC811, UBC812, UBC834, UBC835) were also used in this research. The polymorphism rates for these primers in their study were 66.67%, 70%, 75%, and 50%, respectively. The polymorphism rates observed in this study for the same primers were 100%, 90%, 100%, and 100%, respectively. These differences are attributed to genetic variation between the studied genotypes. The findings highlight the high reliability of these primers as markers for genetic characterization in this study's genotypes. Mahmood et al. (2023) examined 12 almond genotypes using RAPD and ISSR markers, reporting an average of 7.6 polymorphic bands in their ISSR analysis. The PIC values of their ISSR primers ranged from 0.52 to 0.91. They also evaluated the UBC812 primer, assigning it a PIC value of 0.80. In contrast, this study found PIC values for ISSR primers ranging between 0.30 and 0.86, with the UBC812 primer yielding a PIC value of 0.43. This lower PIC value may result from using hybrid genotypes in this study, which generally exhibit reduced genetic diversity compared to distinct varieties. Despite some variations in PIC values, the ISSR marker systems analyzed in this study demonstrated significant discriminatory capacity and produced consistent, reliable results.

Genetic Similarity Analysis Based on ISSR Markers

The dendrogram shown in Figure 3 was obtained from the ISSR marker analysis. The similarity matrix derived from the ISSR analysis revealed that the genetic similarity coefficient between the Venüs and Üstün varieties was 0.85. The genotype most closely related to the Üstün variety is VÜ15, with a genetic similarity coefficient of 0.84. In contrast, the genotype with the least genetic similarity to Üstün is RÜ5, with a similarity coefficient 0.30. Similarly, for the Venüs variety, the genotypes VÜ65 and VÜ24 exhibited the highest genetic similarity, with a coefficient of 0.85, while the genotype RÜ12 showed the most distant genetic similarity, with a coefficient of 0.29. For the Stark Red Gold variety, genotype RÜ8 exhibited the closest genetic similarity, with a coefficient of 0.71, whereas the most distant genotype was VÜ41, with a coefficient of 0.29. The genetic similarity coefficients among the genotypes ranged from 0.20 to 0.95. The genotypes with the least genetic similarity were RÜ12 and RÜ41, with a similarity coefficient of 0.20, while the genotypes with the closest genetic similarity were VÜ92 and VÜ86, with a coefficient of 0.95. These results highlight the genetic diversity among the genotypes and the discriminative power of the ISSR marker system. In a study by Goulão et al. (2001), molecular characterization was performed using AFLP and ISSR markers in plum, and the cophenetic correlation coefficient was reported as 0.73 In our study, 14 ISSR primers were used to analyze the VÜ and RÜ genotypes, and the cophenetic correlation coefficient was found to be 0.82. This high coefficient indicates a strong unity between the similarity matrix and dendrogram, validating the genetic relationships observed.

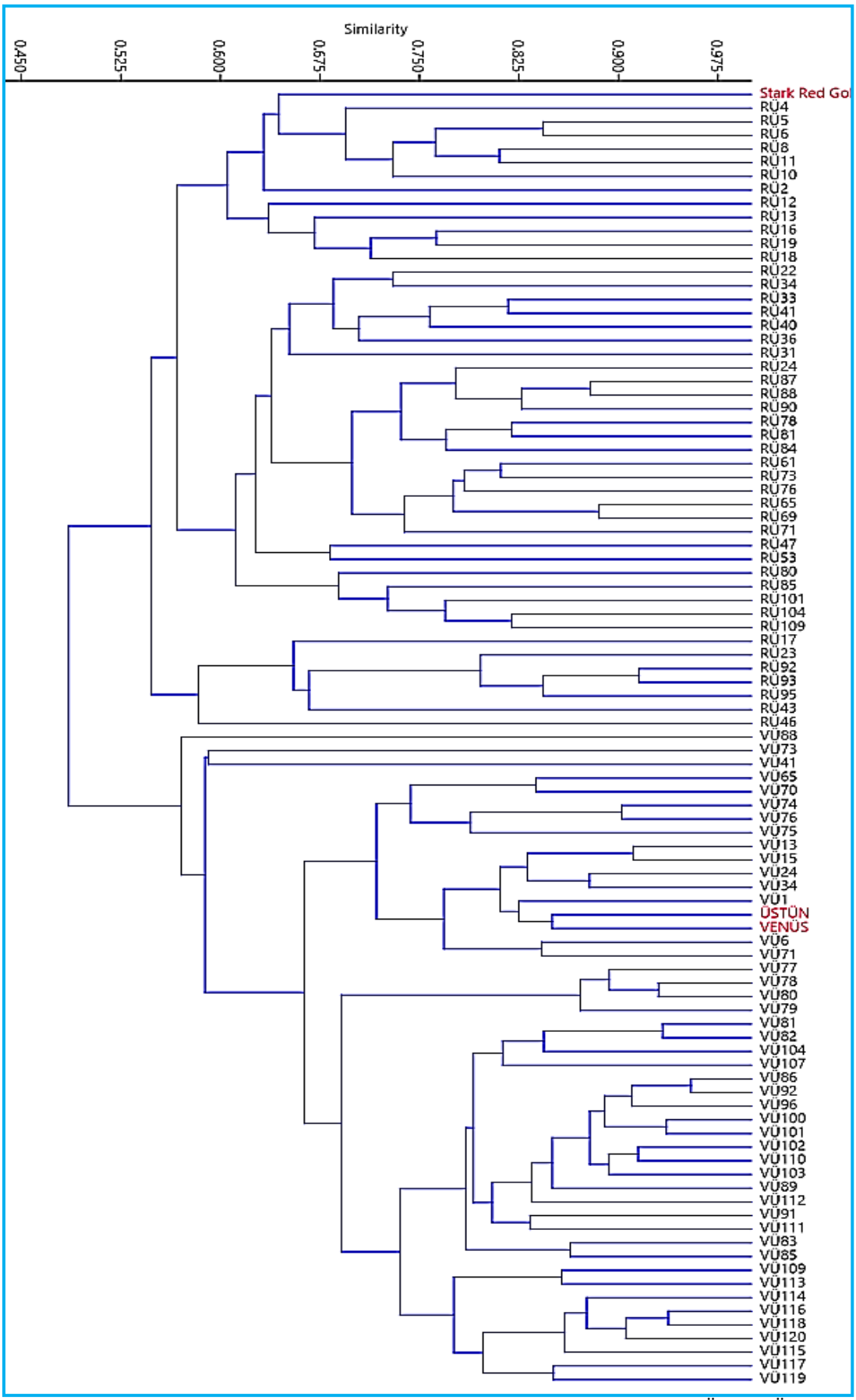

Figure 3. Dendrogram generated using UPGMA, showing relationships between RÜ and VÜ hibrids, using ISSR data.

The PCoA analysis graph, presented in Figure 4, was generated based on ISSR data. The genotypes were distributed evenly across both the negative and positive regions of the coordinate. The two-dimensional graph in Figure 2 explains 21% of the total molecular variation between genotypes in its first and 28% in its second dimensions.

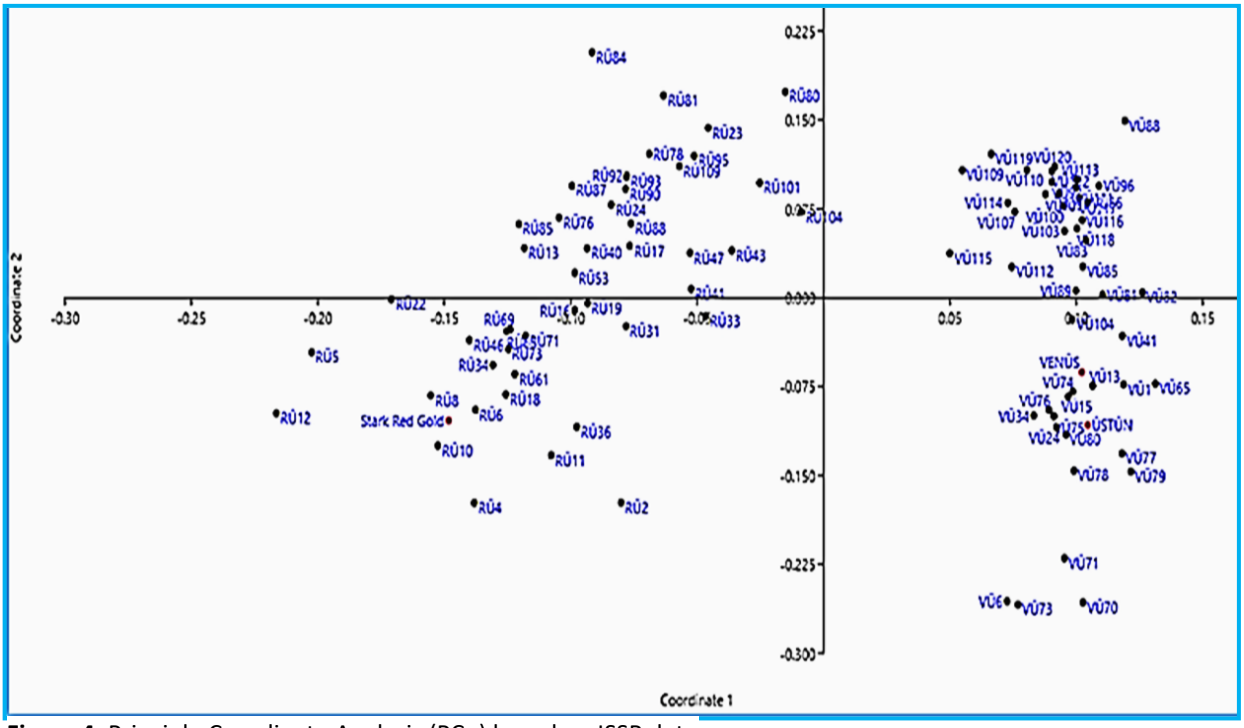

Figure 4. Principle Coordinate Analysis (PCo) based on ISSR data

Cluster analysis based on genetic diversity is the base of plant breeding is one of the important components of biological systems stability. Evaluating genetic diversity in plants for plant breeding programs and heritable resources protection has a vital usage (Ahmadizadeh et al. 2011). The clustering patterns observed through SSR and ISSR analyses offer valuable insights into the genetic structure and diversity of the studied genotypes. In this study, the SSR-based dendrogram revealed that the VÜ-103 genotype was genetically distinct from all other genotypes, indicating a unique genetic background that may be valuable for broadening the genetic base in breeding programs. On the other hand, ISSR markers, demonstrated a clear separation between the VÜ and RÜ genotypes. This suggests a strong genetic divergence between the two groups, which can be strategically utilized to enhance genetic variability through inter-group hybridization.

CONCLUSION

This study investigated the molecular characterization and genetic relationships of peach and nectarine cultivars and their hybrids using 5 SSR and 14 ISSR markers. When comparing the current study's SSR and ISSR analysis data with existing literature, the results emphasized the high discriminatory power of the primers used. These primers proved effective in peach and nectarine genetics and breeding. Future studies should consider increasing the number of primers to gain more comprehensive genetic information about the genomes of Prunus varieties and hybrids. It is also recommended that hybrid individuals be evaluated with molecular data alongside morphological, phenological, pomological, and other traits over the long term. In future breeding efforts, crossbreeding distant genotypes will enhance genetic variation, with molecular data crucial in developing new breeding materials.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

A. B: Performing all analyses, statistical analyses & writing; D.D.: Performing a part of analysis and statistical analyses & editing; S.Ç: Data analysis-review, editing; A.B.K.: Review, editing; Y.A.K.: Supervising, designing of the study, data analysis-writing & editing,

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Performance of Ready-To-Use Isothermal Detection Kits in Plum pox virus (PPV) Detection

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ABSTRACT

Plum pox virus (*Potyvirus plumpoxi*-PPV), one of the most significant diseases affecting stone fruit trees, has been extensively studied worldwide since its initial detection in 1917, with various diagnostic approaches explored. This study investigates the performance of colorimetric and real-time diagnostic kits developed by DOSA Information and Communication Technologies Ltd. for detecting PPV under isothermal conditions. These isothermal diagnostic kits, developed and optimized with domestic resources, stand out as highly practical diagnostic tools, leveraging an advantage of containing proprietary primer sets that enable direct testing of RNA from infected plants, independent of existing isothermal methods. In this study, the isothermal diagnostic kits enabled successful amplification of PPV at 65°C within 60 minutes, without cross-reaction with potential host genomes or other viruses that could co-infect. The colorimetric and real-time diagnostic kits demonstrated detection sensitivities of 10^{-4} and 10^{-5} ng/µL of PPV RNA, respectively, meeting the desired standards for PPV detection. These kits also facilitated effective amplification of PPV-M, D, and T strains, commonly found in Türkiye. Colorimetric and real-time isothermal diagnostic kits can be utilized as rapid and cost-effective tools in PPV screening programs. The application of these kits, especially in field settings and areas with limited laboratory infrastructure, should be encouraged. This successfully developed and optimized isothermal diagnostic platform could also be adapted for the detection of other significant plant viruses, offering a strategic advantage in managing viral diseases in agricultural regions such as Türkiye.

Key words: PPV, Sharka Disease, Isotermal, LAMP, Kit

Kullanıma Hazır Izotermal Tanı Kitlerinin Plum pox virus (PPV) Tanısındaki Performansları

ÖZET

Sert çekirdekli meyve ağaçlarını etkileyen en önemli hastalıklardan birine neden olan Plum pox virus (*Potyvirus plumpoxi*-PPV), ilk tespit edildiği 1917 yılından bu yana dünya çapında kapsamlı bir şekilde incelenmiş ve çeşitli tanı yaklaşımları araştırılmıştır. Bu çalışmada, DOSA Bilgi ve İletişim Teknolojileri Ltd. tarafından izotermal koşullar altında PPV'yi tespit etmek için geliştirilen kolorimetrik ve gerçek zamanlı tanı kitlerinin performansı araştırılmıştır. Yerli kaynaklarla geliştirilen ve optimize edilen bu izotermal tanı kitleri, mevcut izotermal yöntemlerden bağımsız olarak enfekte bitkilerden RNA'nın doğrudan test edilmesine olanak tanıyan tescilli primer setleri içerme avantajından yararlanarak son derece pratik tanı araçları olarak öne çıkmaktadır. Bu çalışmada, izotermal tanı kitleri, potansiyel konukçu genomları veya birlikte enfekte edebilecek diğer virüslerle çapraz reaksiyona girmeden 65°C'de 60 dakika içinde PPV'nin başarılı bir şekilde çoğaltılmasını sağlamıştır. Kolorimetrik ve gerçek zamanlı tanı kitleri, PPV tespiti için istenen standartları karşılayan, sırasıyla 10^{-4} ve 10^{-5} ng/µL PPV RNA tespit hassasiyetini göstermiştir. Bu kitler ayrıca Türkiye'de yaygın olarak bulunan PPV-M, D ve T ırklarının etkili bir şekilde amplifikasyonunu kolaylaştırmıştır. Kolorimetrik ve gerçek zamanlı izotermal tanı kitleri, PPV tarama programlarında hızlı ve uygun maliyetli araçlar olarak kullanılabilir. Bu kitlerin, özellikle saha koşullarında ve sınırlı laboratuvar altyapısına sahip alanlarda uygulanması teşvik edilmelidir. Başarıyla geliştirilen

ve optimize edilen bu izotermal tanı platformu, Türkiye gibi tarım bölgelerinde viral hastalıkların yönetiminde stratejik bir avantaj sunarak diğer önemli bitki virüslerinin tespiti için de uyarlanabilir.

Anahtar kelimeler: PPV, Şarka Hastalığı, İzotermal, LAMP, Kit

INTRODUCTION

PPV belongs to the genus *Potyvirus* within the family *Potyviridae*. The virus has a single-stranded, positive-sense RNA genome approximately 9.8–10 kb in size. The genome has a long poly(A) tail at its 3' end and a protein (VPg) attached to its 5' end. This polyprotein structure is processed into 10 protein products encoded by the virus genome: P3, CP, HCPro, NIa-VPg, P1, 6K1, NIaPro, 6K2, NIb, and CI proteins (Salvador et al. 2006, Koç 2010, Çelik 2020).

The symptoms of PPV, also known as Sharka, vary depending on the virus strain, environmental conditions, host species, and cultivar. The virus typically causes chlorotic streaks and spots on flowers, leaves, and fruits, especially in spring, and also affects seeds, as well as fruit peels (Cambra et al. 2006). PPV is the most significant viral pathogen affecting stone fruit trees, including peach, plum, sour cherry, cherry, and apricot. The virus causes substantial yield and quality losses, rendering the fruit unmarketable (Garcia et al. 2014). Infected plants have shown reductions of 21–34% in fruit density and 0.14–2.11% in sugar content, with increased acidity. A recent study estimated the economic cost of the disease over the 28-year period from 1995 to 2023 at €2.4 × 10^9 (Cambra et al. 2024). PPV causes visible symptoms, especially on leaves, flowers, and petals of peach, apricot, and plum varieties. Similarly, in almonds, PPV causes reduced fruit yield and quality, with deformed fruits and chlorotic leaves, although the symptoms may be rapidly masked (Koç 2010).

The primary reason for the widespread dissemination of the disease is the use of infected propagation materials to establish new orchards. The virus is transmitted by different aphid species, particularly *Myzus persicae*, through a non-persistent mechanism (Cambra et al. 2006).

PPV was first identified in Türkiye approximately fifty years ago on plum trees in Edirne (Sahtiyanci 1969, Kurçman 1973). Subsequent studies have detected the virus in various provinces across the country (Candresse et al. 2007, Akbaş et al. 2011, Serçe et al. 2011, Gürcan and Ceylan 2016, Morca et al. 2020; 2021; 2022, Coşkan et al. 2022). Among the 10 identified PPV strains, only 4 (PPV-D, -M, -Rec, and T) have been detected in Türkiye. Additionally, a unique strain named PPV-Mist has been discovered in Türkiye, specifically in Istanbul. Recent studies have shown that the PPV-D, -M, -Rec, and -T strains have been prevalent in Türkiye for a long time, exhibiting significant genetic diversity and thus being considered native to the region. Various studies indicate that Türkiye is the origin of these four strains, with PPV-T isolates being dominant within the country (Elibüyük 2003, Serçe et al. 2009, Gürcan and Ceylan 2016, Gürcan et al. 2019, Teber et al. 2019, Gürcan et al. 2020, Gürcan et al. 2020, Teber et al. 2023).

For PPV diagnosis, in addition to biological methods, serological methods, particularly the ELISA (Enzyme-Linked Immunosorbent Assay) test, were widely used in the early years. Using monoclonal antibodies has made differentiating and diagnosing variations among virus strains easier. Specifically, D and M strains can be identified using monoclonal antibodies against structural and non-structural PPV proteins.

The ease of application and cost-effectiveness of the ELISA test have made it one of the most preferred techniques for virus diagnosis. However, low virus concentration in plants and high levels of plant inhibitors can sometimes make detecting viral agents via ELISA challenging (Lopez Moya et al. 2000). Therefore, more sensitive molecular methods, such as molecular hybridization and PCR (Polymerase Chain Reaction), have been introduced as alternatives. These techniques enable the accurate diagnosis of agents even at very low concentrations (Koç 2010). In addition to serological tests, serological and molecular techniques, including ELISA and RT-PCR (Reverse Transcription-Polymerase Chain Reaction), have been employed together to detect PPV in various stone fruit species (cherry, peach, apricot, almond, plum, nectarine) exhibiting different symptoms across different regions of Türkiye. These diagnostic methods have been applied to validate one another (Serçe et al. 2009, Koç 2010, Gürcan and Ceylan 2016). Furthermore, in addition to the RT-PCR method, PPV's detection in quantitative analyses, particularly in aphids, has been successfully implemented. Using RT-PCR, SYBR Green, melting curve analysis has been identified as a simple and robust method for identifying and testing various pathogens (Varga and James 2006).

In addition to the methods mentioned above, which are still effectively used in PPV diagnosis today, the Loop-mediated isothermal amplification (LAMP) technique, which is the subject of this study, has been developed for the sensitive, rapid, and high amplification of low amounts of DNA. This technique utilizes a primer set specifically designed to recognize six different regions on the template genome, enabling the reaction (Notomi et al. 2000). A LAMP reaction can be performed using a simple water bath or heat block to maintain 60–65 °C. Amplification results can be determined by agarose gel electrophoresis, and the amplified DNA or

cDNA (Complementary Deoxyribonucleic Acid) can be validated through visual observation in the reaction tube, either with the naked eye or under UV light. Although originally developed for DNA amplification, the LAMP technique has been adapted for the amplification of viral RNA (Ribonucleic Acid) targets under the name RT-LAMP by incorporating a reverse transcriptase enzyme (Varveri et al. 1987, Laín et al. 1989, Candresse et al. 1994, Martin et al. 2000, Notomi et al. 2000, Varga and James 2006; Fernandez-Soto et al. 2014, Panno et al. 2020). It has also been applied to detect plant viruses. Using this method, Varga and James (2006) developed an RT-LAMP procedure for PPV detection, identifying five PPV isolates, including D, M, EA, C, and W strains. Additionally, Hadersdorfer et al. (2011) developed a modified Blue LAMP based on Varga and James' method, which was applied to PPV suspensions obtained from infected plant tissues. In Türkiye, a study by Çelik and Ertunç (2021) developed a classical RT-LAMP method for PPV-T, and findings were evaluated by adding components after the reaction.

In recent years, the adaptability of the LAMP method at non-variable temperatures and its non-requirement for advanced laboratory instrumentation have made it the subject of various studies aiming for potential commercial application. In this study, as supported by the relevant literature mentioned above, the diagnostic performance of locally developed diagnostic kits designed for the rapid colorimetric and real-time detection of PPV-D, PPV-M, and PPV-T strains, which are commonly found in Türkiye, in a single-tube format was investigated.

MATERIALS AND METHODS

Virus Source

The virus isolates used in this study consisted of peach plant parts infected with PPV-M, PPV-T, and PPV-D, stored at -80°C in the Virology Laboratory of the Department of Plant Protection, Faculty of Agriculture, Bolu Abant İzzet Baysal University. The isolates and strain diversity were confirmed by Çelik (2020).

RNA Isolation and DNase treatment

A total of six infected peach leaves (two from each strain) were used in this study. Plant tissues from plums, peaches, apricots, and almonds, which are common hosts of PPV, were subjected to RNA isolation for cross-reaction and specificity tests.

To isolate RNA from plant tissues infected with all three PPV strains and from common hosts, the Nucleozol RNA Isolation Solution (Macherey-Nagel, Germany) was used. The DNase I treatment was performed using Thermo Fisher Scientific DNase I (Catalog Number: EN0525) in accordance with the manufacturer's instructions, with volumetric modifications. A final concentration of 2000 ng/µL total RNA was used in the process.

Kits Used for Isothermal Detection of PPV

This study used detection kits developed by DOSA Information and Science Technologies Biological Development & Research were used to diagnose PPV. These kits enable the colorimetric and real-time isothermal amplification of the three PPV strains prevalent in Türkiye, all within a single reaction tube. Unlike conventional counterparts, the diagnostic kit employed in this study contains specially designed primer sets targeting the coat protein region of PPV for accurate detection. The RT-LAMP test can be conducted directly using viral RNA, allowing results to be evaluated visually or in real time.

Evaluation of Isothermal Test Results

Three different methods were used to assess the results of the reaction. The first method involved observing the color change from pink to yellow in the reaction tubes, which indicates a positive result. This color change was evaluated with the naked eye to confirm the presence of the sample's target nucleic acids (PPV RNA). The second evaluation method utilized agarose gel electrophoresis, following the protocol by Gallitelli and Minafra (1994). This technique allows for the separation and visualization of amplified products based on their size, confirming the presence and specific amplification of PPV-related sequences in the sample. According to the working principle of the real-time kit, amplification curves' formation and development time were monitored at 65°C for 60 minutes, with readings taken every minute on a real-time PCR system (LightCycler® 480; Roche, Basel, Switzerland). This method provides quantitative data on the amplification process, allowing for precise real-time monitoring of the reaction dynamics.

Initial Reaction

According to the manufacturer's instructions, RNA from the PPV-D isolate, along with negative and positive controls provided by the kit, was subjected to colorimetric and real-time reactions at an incubation

temperature of 65°C for 60 minutes. The reaction outcome was evaluated through three methods: direct visual observation of color change, agarose gel electrophoresis, and real-time monitoring of the amplification saturation curve.

Specificity, Sensitivity, and Detection Performance of Isothermal Diagnostic Kits in Common Strains

To determine the specificity of LAMP primers, in addition to PPV-D RNA, the DNA of PPV's natural hosts, such as peach, plum, apricot, and almond, were tested for cross-reactivity. The PPV-D RNA, isolated from plant samples, was employed in sensitivity studies to determine the minimum detectable nucleic acid concentration.

Six different dilutions were made, starting from a 10 ng/µL concentration. These dilution series were used in both colorimetric and real-time reactions to investigate the sensitivity of the kits. The minimum amount of nucleic acid that both kits could amplify was approximately determined. The reaction outcomes were evaluated through both visual observation and real-time PCR monitoring.

Additionally, samples known to be infected with PPV-D, M, and T strains, selected from the isolated pool of the Department of Plant Protection, Faculty of Agriculture, Bolu Abant İzzet Baysal University, were subjected to detection performance reactions in duplicate.

RESULTS AND DISCUSSION

Results

For the initial reaction, 10 ng/µL of PPV-D RNA was used, and both the positive and negative controls provided by the kit were included in the colorimetric and real-time RT-LAMP reactions. At the end of the initial reaction, after approximately 55 minutes, a color change from pink to yellow was observed in the positive control provided by the kit. After 60 minutes, a similar color change was observed in the PPV-D RNA tube (Figure 1a). Additionally, the presence of a ladder-like band pattern, which confirmed positive amplification, was verified by agarose gel electrophoresis (Figure 1b). Furthermore, based on the initial reaction results, real-time RT-LAMP showed that saturation curves indicating positive amplification appeared at approximately the 20th minute in the positive control provided by the kit, and at the 22nd minute in the PPV-D infected sample (Figure 1c). These findings concluded that the colorimetric test kit enabled a color change within 60 minutes, while the real-time test kit allowed amplification to occur in the PPV-D infected sample after approximately 22 minutes.

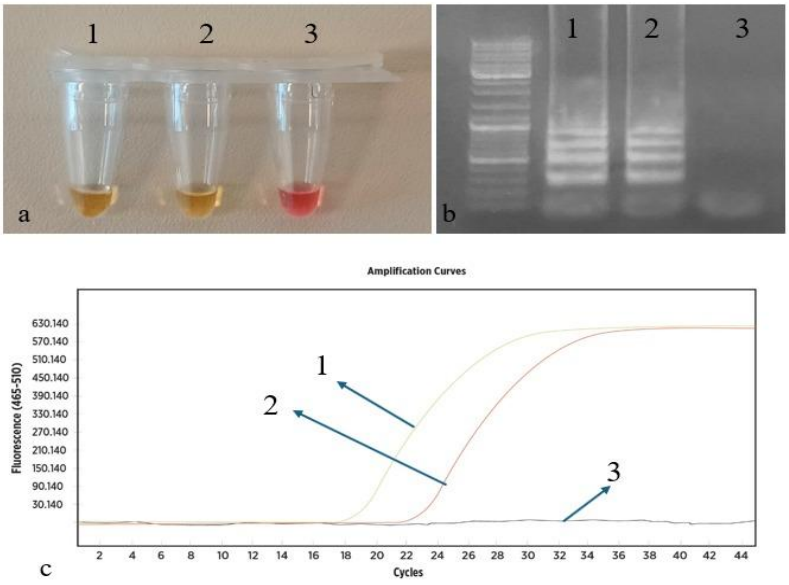

Figure 1. Initial LAMP reaction results. a. Visual evaluation for the colorimetric test after the initial reaction with 60 minutes of incubation at 65°C. b. Agarose gel electrophoresis image showing ladder-like band formation in positive samples. c. Real-time RT-LAMP results indicating amplification with saturation curves at 20 and 22 minutes (1; kit positive control, 2; PPV-D RNA, 3; kit negative control).

RT-LAMP Diagnostic Kit Specificity and Sensitivity Analysis Results

To test the specificity of the isothermal diagnostic kits used, in addition to the PPV-D infected sample, DNA from peach, plum, apricot, and almond, as well as PDV and PNRSV RNAs, were subjected to a 60-minute reaction at 65°C. At the end of the incubation period, no color change was observed in any tube except for the

one containing PPV-D RNA (Figure 2a). Additionally, the results were consistent with the real-time RT-LAMP analysis, where no saturation curves were observed for any RNA other than PPV-D (Figure 2b). Furthermore, no unwanted amplification or banding was detected (Figure 2c). Based on these findings, the developed test kits are highly specific for PPV amplification and do not exhibit cross-reactivity.

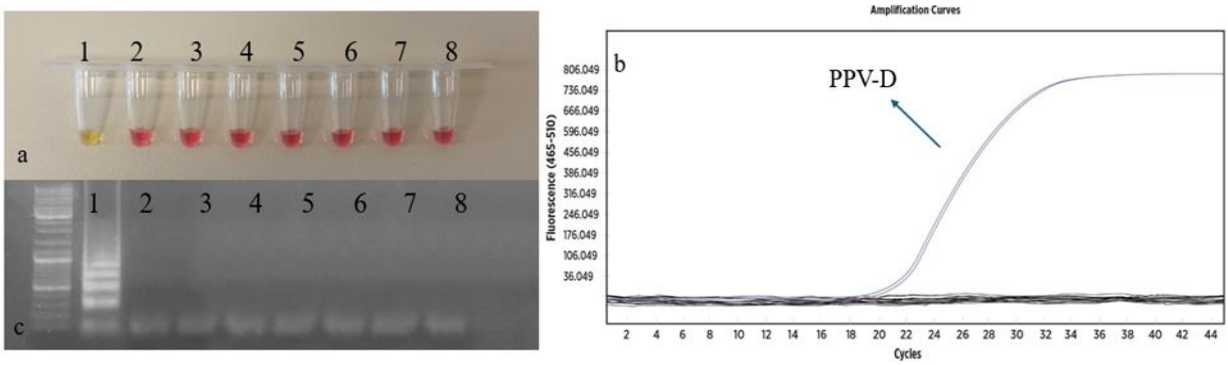

Figure 2. Specificity analysis of developed kits a. Color change observed in tube 1 containing PPV-D RNA after a 60-minute reaction, b. Saturation curve indicating amplification in PPV-D infected sample (tube 1) observed via real-time LAMP, c. Agarose gel electrophoresis images confirming amplifications (2; peach DNA, 3; plum DNA, 4; apricot DNA, 5; almond DNA, 6; PNRSV RNA, 7; PDV RNA, 8; kit negative control, 9; water control. Real-time RT-LAMP test was conducted in duplicate).

To determine the detection levels of the developed diagnostic kits, dilution series adjusted within the range of 10^{-6} to 10^{-4} ng/µL were reacted. The colorimetric reaction results showed that PPV RNA at a concentration of 10^{-4} ng/µL could be successfully amplified (Figure 3a), while in the real-time RT-LAMP test, amplification was detected in the sample with a concentration of 10^{-5} ng/µL (Figure 3b). However, as the RNA amount decreased, it was observed that the saturation curves in the real-time kit formed later. No unwanted amplification bands were observed (Figure 3c). Additionally, it was noted that as the RNA concentration decreased, the color change in the colorimetric reaction became harder to distinguish. Based on these findings, it can be concluded that the developed diagnostic kits can successfully amplify PPV RNA up to 10^{-4} and 10^{-5} ng/µL.

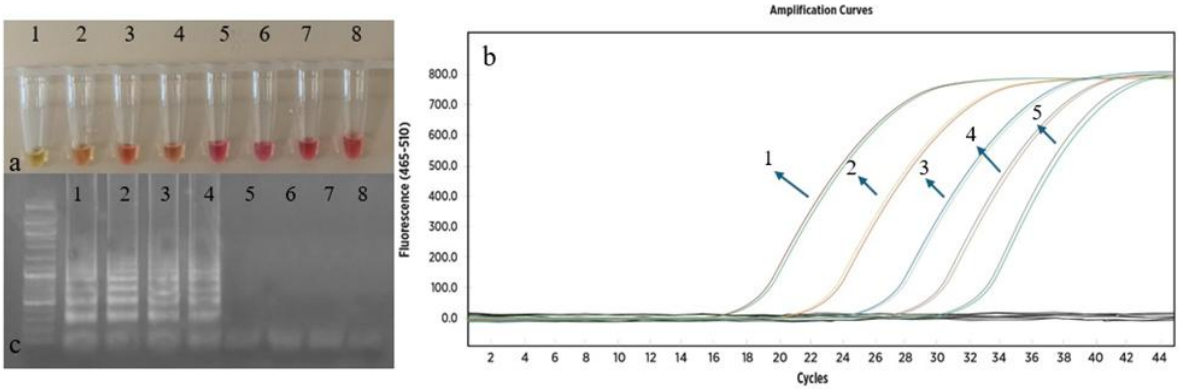

Figure 3. Sensitivity Levels of the Diagnostic Kits Used. a. Visual representation of amplifications in the colorimetric reaction. b. Saturation curves obtained with the real-time kit. c. Agarose gel images confirming amplifications (Dilution series from 10^{-6} to 10^{-4} were used in the experiments, with real-time RT-LAMP tests performed in duplicate for the samples).

Testing of Isothermal Diagnostic Kits on Samples Infected with Three PPV Strains

Three RNA samples, selected from the isolated pool in the Virology Laboratory of the Plant Protection Department at Bolu Abant İzzet Baysal University, which is known to be infected with PPV-D, M, and T strains, were tested in duplicate. According to the colorimetric RT-LAMP reaction results carried out at 65°C for 60 minutes, all three PPV strains were successfully amplified (Figure 4a). Additionally, real-time RT-LAMP analysis revealed that saturation curves for real-time amplification appeared after 22 minutes for each strain (Figure 4b). Gel images confirming the amplification were also obtained (Figure 4c). These findings conclude that the developed isothermal diagnostic kits successfully detect the widely found PPV-D, M, and T strains in Türkiye.

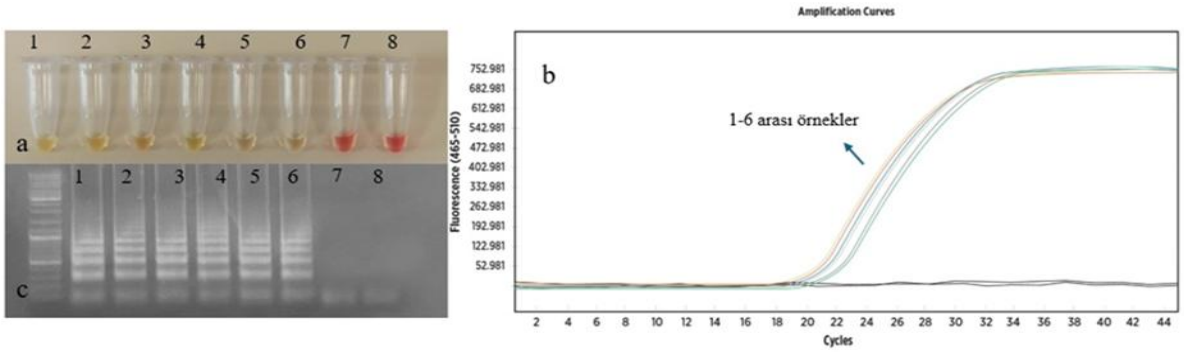

Figure 4. Detection of PPV-D (1 and 2), M (3 and 4), and T (5 and 6) strains using the developed isothermal diagnostic kit, a. Visual color change observed for the three strains in the colorimetric reaction, b. Saturation curves observed in the real-time LAMP test, c. Agarose gel electrophoresis images, 7. kit negative control, 8. water control.

Discussion

This paper addresses the detection of PPV, a significant viral issue in *Prunus* species, using isothermal diagnostic methods. The virus can infect stone fruit species such as apricot, peach, almond, plum, and cherry and is widely disseminated via infected propagation materials. Since its first detection in 1917, many studies have reported the virus spreading to different countries (Atanassov 1932, Levy et al. 2000, Thompson et al. 2001, Spiegel et al. 2004, Navratil et al. 2005, Zotto et al. 2006, Gürcan and Ceylan 2016). Despite over a century since its first detection, the spread of PPV continues to increase, and quarantine and eradication measures are still being applied globally and nationally (Akbaş et al. 2023). This situation has led PPV to maintain its position as a major stone fruit viral disease and remains the subject of numerous studies. The global and specific situation of PPV in Türkiye has prompted this research.

Various methods have been applied for PPV detection to date. Among these methods, biological indexing (Akbaş et al. 2011), ELISA, PCR, and sequencing techniques have been used (Gürcan and Ceylan 2016, Akbaş et al. 2023). Varga and James (2006) developed the RT-LAMP procedure for PPV detection and reported detecting five PPV isolates, including D, M, EA, C, and W, using the RT-LAMP method. Additionally, Hadersdorfer et al. (2011) modified the method developed by Varga and James with Blue LAMP and applied it to PPV suspensions from infected plant tissues. Furthermore, research on classical LAMP methods for PPV-T, a strain found in significant concentration in Türkiye has been conducted (Çelik and Ertunç 2021). The isothermal detection studies of PPV mentioned above emphasize the preparation of external primer sets, optimization, and the need for agarose gel electrophoresis, making these studies stand out. Some studies show that minimizing the components of a LAMP reaction and using single-tube assessments reduce the risk of false-positive results (Sarkes et al. 2020, Çelik and Morca 2021, Golabi et al. 2021, Lalli et al. 2021, Peltzer et al. 2021). This consideration makes simplified, ready-to-use, and practical LAMP reactions preferable.

In this study, contrary to the mentioned studies, two ready-to-use isothermal diagnostic kits were investigated for colorimetric and real-time detection of PPV performance. These kits offer a practical detection method by directly amplifying PPV RNA, thanks to special primer sets that differentiate them from other isothermal methods.

Various studies have explored the development and validation processes of ready-to-use diagnostic kits with different organisms (Cook et al. 2015, Kaarj et al. 2018, Moehling et al. 2021, Jawla et al. 2023). However, ready-to-use isothermal diagnostic kits in plant pathology are limited. We are aware of the existence of the AmplifyRP® Acceler8® isothermal real-time diagnostic kit (ACS 31505/0008) for PPV. However, as this product could not be obtained in the present study, a performance comparison could not be made.

Specificity studies are crucial for proving the reliability of all methods. The isothermal diagnostic kits used in this study successfully facilitated PPV amplification and showed no cross-reaction with the potential host genomes or other viruses that may share common infections. This indicates that the developed diagnostic kits are specific to PPV. Since its development by Notomi et al. (2000), the LAMP method has been used as a highly target-specific diagnostic tool. Various LAMP studies in plant virology have demonstrated that the reactions were aimed at the target organism and did not cause cross-reactive positive amplification (Çelik and Ertunç 2021, Çelik and Morca 2021, Çelik et al. 2024). The specific findings obtained in this study align with those of previous studies, supporting the intended development goals of the LAMP technique.

A diagnostic protocol is expected to have a high sensitivity level. In this study, the colorimetric and real-time diagnostic kits successfully detected PPV RNA at 10-4 and 10-5 ng/µL sensitivity levels, reaching the desired

thresholds. Compatible with our findings, several studies show that isothermal diagnostic methods offer higher sensitivity compared to alternative methods (Zhao et al. 2015, Suzuki et al. 2016, Iftikhar et al. 2020, Sarkes et al. 2020, Stehlíková et al. 2020). The findings in this study indicate that the isothermal diagnostic kits used here have very high detection sensitivity.

Besides possessing strong sensitivity and target specificity, a diagnostic protocol should also be comprehensive for the target organism. The isothermal diagnostic kits used in this study enabled successful amplification of PPV strains D, M, and T found in Türkiye. The findings are consistent with previous studies on PPV (Varga and James 2006, Hadersdorfer et al. 2011, Çelik and Ertunç 2021). This inclusivity is likely due to the selection of the virus's coat protein region as the target region for detection.

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Author Contributions

A.Ç. designed the study and supervised the experiments, S.Y.A and B.Ö contributed in methodology of experiments and supply of detection kits, A.F.M made contributions in validation, K.R. was responsible for conducting all experiments and writing original draft.

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Original Article

Comparison of Total Phenolic Contents and Antioxidant Activities of Ripe and Unripe Fig (*Ficus carica* L.) Extracts Using Different Solvents

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ABSTRACT

This study aimed to evaluate the effects of solvent polarity and fruit maturity on the antioxidant potential and total phenolic content of fig (*Ficus carica* L.) extracts. Unripe and ripe fig fruits collected from the Akseki district of Antalya, Türkiye, were extracted using three different solvents: ethanol, acetone, and ethyl acetate. The extraction yield, total phenolic content (TPC), total antioxidant capacity (TAC), and antioxidant activity (DPPH assay) were determined for each extract. In this study, extraction yield varied depending on both the type of solvent and the ripening stage of the fig. Ethanol was the most efficient solvent, particularly for ripe samples, yielding up to 80.3%. The highest TPC was observed in the ripe–acetone extract (3976.2 ± 526.5 mg GAE/kg DW), while the ripe–ethyl acetate extract exhibited the highest TAC (48.8 ± 0.87 mg AE/g DW). Antioxidant activity measured by the DPPH assay was greatest in the ripe–ethyl acetate extract (57.6 ± 10.37 mmol TE/kg DW). Among the tested extracts, the ripe–ethyl acetate extract exhibited the most favorable antioxidant properties, highlighting its potential as a promising source of bioactive compounds for functional applications. These results suggest that solvent polarity and fruit maturity interact to influence the extractability of phenolic compounds and antioxidant capacity. Semi-polar solvents such as acetone and ethyl acetate enhanced the recovery of bioactive compounds in both unripe and ripe samples, although the effectiveness varied depending on the specific antioxidant parameter evaluated. This study provides comparative data that may contribute to the optimization of extraction strategies for developing natural antioxidant sources from fig fruits.

Key words: Antioxidant activity, *Ficus carica*, Fig, Phenolic content, Ripening stage.

Farklı Çözücüler Kullanılarak Elde Edilen Ham ve Olgun İncir (*Ficus carica* L.) Ekstraktlarında Toplam Fenolik İçeriği ve Antioksidan Aktivitenin Karşılaştırılması

ÖZ

Bu çalışma, çözücü polaritesi ile meyve olgunluk düzeyinin incir (*Ficus carica* L.) ekstraktlarının toplam fenolik içeriği ve antioksidan potansiyeli üzerindeki etkilerini değerlendirmeyi amaçlamıştır. Antalya ili Akseki ilçesinden toplanan ham ve olgun incir meyveleri; etanol, aseton ve etil asetat olmak üzere üç farklı çözücü kullanılarak ekstrakte edilmiştir. Her bir ekstrakt için ekstraksiyon verimi, toplam fenolik madde içeriği (TPC), toplam antioksidan kapasite (TAC) ve antioksidan aktivite (DPPH yöntemi) analiz edilmiştir. Bu çalışmada, ekstraksiyon veriminin hem kullanılan çözücü türüne hem de incir meyvesinin olgunluk aşamasına bağlı olarak değişkenlik gösterdiği belirlenmiştir. Özellikle olgun meyve örneklerinde etanol, %80.3'e ulaşan verimle en yüksek ekstraksiyon etkinliğini sağlamıştır. En yüksek TPC, olgun–aseton ekstraktında (3976.2 ± 526.5 mg GAE/kg kuru madde) saptanırken; TAC açısından en yüksek değer, olgun–etil asetat ekstraktında ölçülmüştür (48.8 ± 0.87 mg AE/g kuru madde). Benzer şekilde, DPPH yöntemiyle belirlenen antioksidan aktivite de en yüksek düzeye

olgun–etil asetat ekstraktında ulaşmıştır (57.6 ± 10.37 mmol TE/kg kuru madde). Elde edilen bulgular doğrultusunda, değerlendirilen ekstraktlar arasında olgun–etil asetat ekstraktı, güçlü antioksidan özellikleriyle öne çıkmakta olup, fonksiyonel uygulamalarda değerlendirilebilecek potansiyel bir biyoaktif bileşik kaynağı olarak dikkat çekmektedir. Elde edilen sonuçlar, çözücü polaritesi ile meyve olgunluğunun fenolik bileşiklerin ve antioksidan kapasitenin ekstrakte edilebilirliğini birlikte etkilediğini göstermektedir. Yarı-polar çözücüler olan aseton ve etil asetat, hem ham hem de olgun örneklerde biyoaktif bileşiklerin geri kazanımını artırmış; ancak bu etkinlik, değerlendirilen antioksidan parametreye göre değişiklik göstermiştir. Bu çalışma, incir meyvelerinden doğal antioksidan kaynaklarının geliştirilmesine yönelik ekstraksiyon stratejilerinin optimize edilmesine katkı sağlayabilecek karşılaştırmalı veriler sunmaktadır.

Anahtar kelimeler: Antioksidan aktivite, *Ficus carica*, Fenolik içerik, İncir, Meyve olgunluğu

INTRODUCTION

Fig (*Ficus carica* L.), a member of the Moraceae family, is one of the oldest cultivated fruit species and has long been appreciated for its nutritional and medicinal properties (Badgujar et al., 2014). In Türkiye, particularly in the Mediterranean region, fig cultivation holds both economic and cultural importance (Çalışkan and Dalkılıç, 2022). The fig fruit is a syconium, a compound structure with numerous small flowers lining the inside of a fleshy receptacle. Its outer peel, which may vary in color depending on the cultivar, contains significant levels of bioactive compounds such as pigments, tannins, and volatile substances that contribute to the overall antioxidant potential (Hajam and Saleem, 2022; Li et al., 2013). Figs can be consumed fresh or dried, and their composition—especially phenolic and antioxidant compounds—may vary depending on the maturity stage and extraction method used.

Figs are a rich source of bioactive compounds, particularly phenolics and flavonoids, which contribute significantly to their antioxidant potential (Oliveira et al., 2009; Harzallah et al., 2016). Several studies have identified phenolic constituents in fig extracts, such as quercetin derivatives, rutin, chlorogenic acid, and various organic acids, all of which play a role in scavenging free radicals and mitigating oxidative stress (Oliveira et al., 2009; Vallejo et al., 2012). These compounds contribute significantly to the fruit's antioxidant capacity and potential health benefits. Organic acids such as oxalic, citric, malic, quinic, shikimic, and fumaric acids have also been identified in fig extracts, which may play a role in flavor as well as bioactivity (Oliveira et al., 2009). Moreover, fig fruits contain pigments including carotenoids and α-tocopherol (vitamin E), both of which are known for their strong antioxidant properties (Solomon et al., 2006; Slavin, 2006). Oxidative stress, caused by excessive reactive oxygen species (ROS), contributes to cellular damage and the progression of various diseases. Phenolic compounds found in figs help mitigate this damage by supporting redox balance through multiple antioxidant mechanisms. These include acting as reducing agents, scavenging singlet oxygen, donating hydrogen atoms, and chelating metal ions (Ouchemoukh et al., 2012; Sirisha et al., 2010). These compounds help prevent oxidative stress-related conditions such as cancer, cardiovascular diseases, neurodegenerative disorders, and diabetes by inhibiting free radical formation and enhancing cellular defense systems (Sirisha et al., 2010). In this context, the fig fruit stands out as a significant source of natural antioxidants—including phenolics, flavonoids, carotenoids, and tocopherols—making it a valuable component of health-promoting diets. The effectiveness of these bioactive compounds is influenced not only by their concentration but also by factors such as ripeness stage and solvent polarity during extraction, which may alter their bioavailability and antioxidant potency (Harzallah et al., 2016; Hajam and Saleem, 2022; Li et al., 2013). The quantification of bioactive compounds in plant materials is significantly influenced by the choice of solvent used during extraction. The polarity of solvents such as ethanol, acetone, and ethyl acetate plays a pivotal role in the selective recovery of phenolic compounds and antioxidants from plant matrices (Hajam and Saleem, 2022; Li et al., 2013). Given that different phenolics exhibit varying solubility in polar and semi-polar solvents, optimizing solvent type is critical for maximizing the yield and antioxidant potential of extracts (Mujic et al., 2012). Moreover, the phytochemical composition of fig fruits can vary depending on their ripening stage, with several studies indicating that unripe and ripe fruits may differ in terms of their phenolic content and antioxidant activity (Pereira et al., 2017; Karantzi et al., 2021). These factors—solvent polarity and fruit maturity—must therefore be considered in evaluating the nutraceutical potential of fig-derived extracts.

Although several studies have reported the presence of phenolic compounds and antioxidant activities in fig, most have focused on either a single extraction solvent or a specific fruit maturity stage. There remains a lack of comprehensive data that simultaneously compare multiple solvents and the maturity-dependent variations in bioactive compound content. One of the most critical factors influencing the extraction efficiency of phenolics and their associated antioxidant activity is the type of solvent used during extraction (Ngo et al., 2017). Polar and semi-polar solvents are commonly employed for recovering phenolic compounds from plant materials due to

their ability to solubilize a wide range of phytochemicals (Do et al., 2014). Ethanol, acetone, and ethyl acetate were selected in this study to represent a range of polarities and extraction capabilities. Ethanol is widely used in food and nutraceutical applications and has been reported to be effective in extracting hydrophilic phenolic compounds (Burdock et al., 2004; Do et al., 2014). Acetone has been found suitable for extracting a broad spectrum of phenolics, including higher molecular weight flavanols (Do et al., 2014), while ethyl acetate, a medium-polar solvent, is effective for extracting moderately polar compounds such as flavonoid aglycones and certain phenolic acids [Kaewseejan et al., 2015). Since the extraction performance of solvents is also influenced by the plant matrix and tissue type, no universal solvent system can be recommended for all plant materials (Wijekoon et al., 2011). Comparative analyses involving these three solvents, particularly in both unripe and ripe fig samples, are still limited in the current literature. Addressing this gap could provide valuable insights into how extraction conditions and fruit developmental stages influence the phenolic composition and antioxidant capacity of fig extracts.

In this study, total phenolic contents and antioxidant capacities of unripe and ripe fig fruits were investigated using three different extraction solvents: ethanol, acetone, and ethyl acetate. The aim was to evaluate how solvent polarity and ripening stage affect the phytochemical profile and antioxidant activity of fig extracts. By conducting a comparative analysis, this study seeks to provide useful data for optimizing extraction strategies in the development of natural antioxidant sources from fig fruits.

MATERIALS AND METHODS

Chemicals

Analytical grade reagents including acetone (Sigma-Aldrich, 90872), ethyl acetate (Sigma-Aldrich, 58958), ethanol (Sigma-Aldrich, 493511), gallic acid (Sigma-Aldrich, G7384), ascorbic acid (Sigma-Aldrich, PHR1008), Trolox (Sigma-Aldrich, 238813), Folin–Ciocalteu reagent (Sigma-Aldrich, F9252), sulfuric acid (Sigma-Aldrich, 339741), sodium phosphate (Sigma-Aldrich, 342483), ammonium molybdate (Sigma-Aldrich, 277908), sodium carbonate (Sigma-Aldrich, S7795), and 2,2′-diphenyl-1-picrylhydrazyl (DPPH; Sigma-Aldrich, D9132) were used without further purification.

Plant Material

Unripe and ripe fig fruits were collected in August 2016 from a local genotype cultivated in the Akseki district of Antalya, Türkiye (coordinates: 37° 02′ 23″ N, 31° 46′ 48″ E; elevation: 1110 meters). Both unripe and ripe fruits were harvested from the same trees during the same period. Unripe fruits were identified by their firm texture, green outer skin, and bland taste, whereas ripe fruits exhibited a softer texture, purplish skin, and a distinctly sweeter flavor. The taxonomic identification of the plant material was confirmed according to the *Flora of Turkey and the East Aegean Islands* (Davis, P.H., 1965–1988). Immediately after collection, all fruit samples were frozen at −80 °C to preserve their phytochemical integrity until further processing.

Extractions of fig

Freshly harvested fig fruits were first freeze-dried using a lyophilizer (Scanvac CoolSafe Freeze Dryer, LaboGene, Denmark), then finely ground and stored at −20 °C until use. For the extraction process, 1 g of fig powder was combined with 80 mL of ethanol, ethyl acetate, or acetone (solid-to-solvent ratio 1:80, w/v), and homogenized at 10,000 rpm for 2 minute using a remote-controlled homogenizer (WiseTis, Witeg, Germany) (Tram et al., 2015). The homogenized mixtures were centrifuged at 4000 × g for 10 minutes at 4 °C, and the resulting supernatants were filtered through Whatman No. 1 filter paper. The pooled extracts were then evaporated under reduced pressure at 40 °C using a rotary evaporator (Scilogex RE100-Pro, USA) to remove the solvents. The dried fig extracts were stored at −20 °C until analysis. A total of six different fig extracts were prepared: unripe-ethanol, ripe-ethanol, unripe-ethyl acetate, ripe-ethyl acetate, unripe-acetone, and ripe-acetone. The extraction yield (%) was calculated using the following equation:

$$\text{Extraction yield (\%)} = \frac{\text{Total weight of extract obtained (g)}}{\text{Total weight of powered plant material (g)}} \times 100$$

Extraction yield was calculated from a single experiment per sample due to material limitations. Therefore, no standard deviation is provided for yield values. This represents a limitation of the study and should be considered when interpreting extraction efficiency results.

Determination of Total Phenolic Content (TPC)

The total phenolic content (TPC) of the fig extracts was determined using the Folin–Ciocalteu colorimetric method, based on the procedure originally described by Slinkard and Singleton (1977). Briefly, 0.5 mL of the extract was mixed with 2.5 mL of 0.2 N Folin–Ciocalteu reagent, followed by the addition of 2.0 mL sodium carbonate solution (75 g/L). The reaction mixture was incubated in the dark at room temperature for 2 hours. Absorbance was measured at 765 nm using a Multiskan-90 spectrophotometer (Thermo Scientific, USA). TPC values were calculated from a standard curve prepared with gallic acid (concentration range: 5 –100 ppm, $R^2 = 0.9966$) and expressed as milligrams of gallic acid equivalents (GAE) per 100 grams of dry extract weight (DW).

Total Antioxidant Capacity (TAC)

The total antioxidant capacity (TAC) of the extracts was evaluated via the phosphomolybdenum assay, as described by Prieto et al. (1999). For each sample, 0.1 mL of extract was added to 1 mL of reagent mixture containing 0.6 M sulfuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate. The resulting solution was incubated at 95 °C for 90 minutes using a temperature-controlled heat block. After cooling the samples to room temperature, absorbance was recorded at 695 nm. The TAC was quantified using an ascorbic acid calibration curve (concentration range: 0.03125–0.5 mg/mL, $R^2 = 0.9987$) and results were presented as milligrams of ascorbic acid equivalents (AE) per gram of dry weight (DW).

Antioxidant Activity (DPPH)

The antioxidant activity of the fig extracts was determined using the DPPH (2,2′-diphenyl-1-picrylhydrazyl) free radical scavenging method, following the approach outlined by Brand-Williams et al. (1995), with slight modifications. In this assay, 0.1 mL of fig extract was added to 3.9 mL of a methanolic DPPH solution (6×10^{-5} M). The mixture was allowed to stand in the dark at approximately 25 °C for 30 minutes. After incubation, the absorbance of the solution was measured at 515 nm. The antioxidant activity was expressed as millimoles of Trolox equivalents (TE) per kilogram of dry weight (DW), based on a standard curve prepared with Trolox solutions (concentration range: 0.03–0.5 mM; $R^2 = 0.9970$).

Statistical Analysis

All experimental data were obtained from at least three independent replicates. The results are expressed as mean ± standard deviation (SD). Statistical analysis was performed using GraphPad Prism (version 5.0; GraphPad Software, San Diego, CA, USA). Unpaired two-tailed t-tests were used to compare ripe and unripe fig samples within each solvent group (P1). One-way ANOVA followed by Tukey's post hoc test was conducted to evaluate differences among extraction solvents (P2). A p-value of less than 0.05 was considered statistically significant ($*p < 0.05$, $**p < 0.01$, $***p < 0.001$).

RESULTS AND DISCUSSION

Extraction Yield

The extraction yields obtained in this study demonstrated a clear dependence on both the type of solvent and the ripening stage of the fig fruits. Ethanol was the most efficient solvent, particularly in ripe samples, yielding 80.3%, while acetone and ethyl acetate resulted in considerably lower yields (17.3% and 7.1%, respectively). These values are substantially higher than those reported in previous studies on *Ficus carica*, where yields typically ranged between 9.95% and 11.47% using pure methanol or mixed solvents (Soni et al., 2023; Kebal et al., 2024). This difference may be attributed to the use of fruit tissue rather than leaves, the polarity of ethanol, and the homogenization-assisted extraction method employed in the present study. It is well established that extraction yield is strongly influenced by plant matrix, solvent polarity, and extraction parameters (Soni et al., 2023).

Interestingly, the ripe–ethanol extract yielded significantly more than its unripe counterpart (26.5%), suggesting that ripening enhances extractability. This effect may result from structural changes in the cell wall or increased moisture content during ripening, which facilitate solvent penetration (Li et al., 2010). In contrast, ethyl acetate yielded less extract from ripe fruits. This reduction may be due to the degradation or transformation of semi-polar phenolics during ripening, such as aglycones or certain esters, which are more efficiently extracted by ethyl acetate. Ripening is also known to shift the metabolite profile toward more hydrophilic compounds, including sugars and organic acids, which are poorly soluble in ethyl acetate (Ydjedd et al., 2017). As a result, the reduced abundance of semi-polar extractable components may explain the lower yield obtained with ethyl acetate in ripe samples.

It is also important to consider that extraction yield reflects not only phenolic content but also the presence of other soluble compounds. As previously reported, substances such as proteins, carbohydrates, and sugars can contribute to higher extraction yields when extracted with polar solvents like ethanol or water (Zieliński and Kozłowska, 2000). This may partly account for the significantly higher yield observed in the ethanol–ripe group, where both phenolics and other co-extracted components may have contributed to the total yield. Therefore, the combined influence of solvent polarity, fruit developmental stage, and co-extractable non-phenolic compounds should be considered when evaluating extraction efficiency.

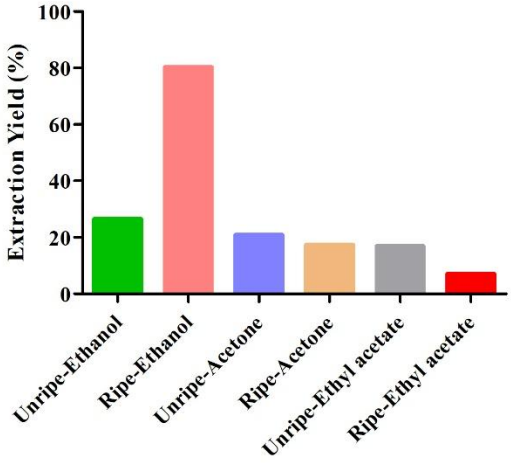

Figure 1. Extraction yields (%) of unripe and ripe fig extracts obtained using different solvents.

Total Phenolic Content (TPC)

The total phenolic contents of fig extracts varied depending on both the ripening stage and the solvent used for extraction. Phenolic contents were expressed as gallic acid equivalents (GAE), based on a standard curve generated from gallic acid solutions (Figure 2A). In unripe fig samples, the highest phenolic concentration was observed in the acetone extract (3680.25 ± 186.75 mg GAE/kg DW), followed by ethanol (1333.2 ± 49.4 mg GAE/kg DW) and ethyl acetate (595.7 ± 334.6 mg GAE/kg DW). For ripe fig samples, phenolic content was highest in the acetone extract (3976.2 ± 526.5 mg GAE/kg DW), followed by ethyl acetate (1220.45 ± 50.95 mg GAE/kg DW) and ethanol (153.65 ± 52.15 mg GAE/kg DW) (Figure 2B and Table 1). A statistically significant difference was observed between unripe and ripe ethanol extracts ($p = 0.0387$), indicating a marked decrease in phenolic content upon ripening, while no significant differences were found for acetone ($p = 0.6869$) or ethyl acetate ($p = 0.3161$) extracts. Overall, phenolic content was significantly influenced by solvent type ($p = 0.0002$), highlighting the importance of extraction conditions and suggesting that ethanol extraction is more sensitive to maturity-related changes in phenolic composition compared to acetone and ethyl acetate.

The TPC values obtained in this study fall within a wide range of previously reported data but are generally higher than many earlier findings. For instance, Bayrak et al. (2023) reported TPC values ranging between 35.98 and 47.30 mg GAE/100 g fresh weight (FW) for methanolic extracts of green to dark purple fig varieties from Türkiye's Black Sea region. Converting these values to dry weight basis (assuming ~80% moisture), the estimated range would be approximately 180–236 mg GAE/kg DW, which is considerably lower than our findings. Similarly, Ayoub et al. (2019) reported a TPC of 96.46 µg GAE/mg extract (i.e., 96.46 mg GAE/g = 96,460 mg GAE/kg DW), which is significantly higher than our results, likely due to differences in plant part (leaves vs. fruit), extraction solvent, or sample origin.

Kebal et al. (2022) also reported variable TPC levels among fig varieties, with light peel types having lower values (~730.88 mg GAE/100 g FW) and darker types showing higher values (~951.06 mg GAE/100 g FW). Again, when these are adjusted to dry weight, they reflect much higher values, supporting the idea that fig phenolic content is strongly influenced by variety and peel pigmentation. Furthermore, previous studies have reported extreme variation in phenolic concentrations depending on fig variety and peel color, with total phenolic contents ranging from as low as 19.4 mg GAE/100 g FW to as high as 6147 mg GAE/100 g FW in fresh fig fruits (Caliskan and Polat, 2011; Harzallah et al., 2016; Konak et al., 2017). The relatively high TPC values observed in our study, particularly in acetone– unripe extracts, may be attributed to both the intermediate polarity of acetone and the greater abundance of extractable phenolics in unripe fig tissue. Additionally, differences in geographical origin, genotype, solvent system, and extraction methodology can all contribute to the variability

seen across studies. These findings underscore the importance of standardizing sample preparation and solvent selection when comparing phenolic contents across fig varieties.

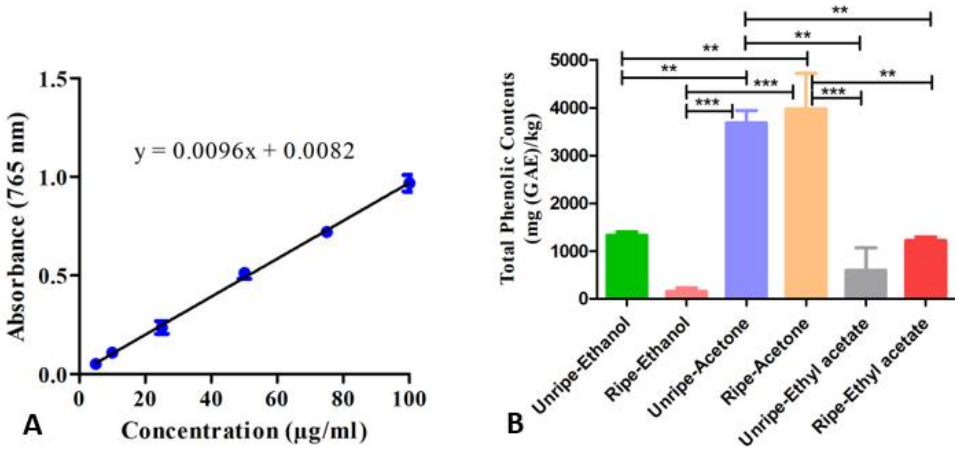

Figure 2. A) Gallic acid standard graph. **B)** Total phenolic contents (mg GAE/kg) of unripe and ripe fig extracts obtained using different solvents (ethanol, acetone, and ethyl acetate). The error bars represent the standard deviation (SD) of three independent measurements (*p < 0.05, **p < 0.01, ***p < 0.001).

Total Antioxidant Capacity (TAC)

The total antioxidant capacity (TAC) of fig extracts varied according to both the solvent type and the ripening stage of the fruit. Total antioxidant capacity was expressed as ascorbic acid equivalents (AE), calculated based on a standard curve prepared with ascorbic acid solutions (Figure 3A). In unripe fig samples, total antioxidant capacity (TAC) was measured as 22.9 ± 0.51 mg AE/g for ethanol, 27.3 ± 0.82 mg AE/g for acetone, and 15.2 ± 0.11 mg AE/g for ethyl acetate. In ripe samples, TAC values significantly increased in acetone (41.9 ± 0.76 mg AE/g, $p = 0.0484$) and ethyl acetate (48.8 ± 0.87 mg AE/g, $p = 0.0166$) extracts, while a significant decrease was observed in the ethanol extract (8.6 ± 0.06 mg AE/g, $p = 0.0227$) (Figure 3B and Table 1). Among all tested samples, the highest TAC was recorded in ripe figs extracted with ethyl acetate. Statistical analysis revealed that the extraction solvent had a significant effect on TAC values ($p < 0.0001$), emphasizing the impact of solvent polarity. These findings indicate that both the choice of solvent and the maturity stage of the fruit substantially influence the antioxidant capacity of fig extracts, with ethyl acetate demonstrating superior extraction efficiency in ripe samples.

Although the phosphomolybdenum assay has been less frequently applied in fig-related studies, contextual comparisons can still be made using alternative antioxidant assays such as DPPH, ABTS, and FRAP. For instance, Konak et al. (2017) reported DPPH radical scavenging activities of dried fig extracts ranging from 387.26 to 462.16 µmol TE/100 g DM, while Kamiloglu and Capanoglu (2015) measured ABTS values between 222 and 255 mg TE/100 g DM in dried and fresh Turkish figs. In comparison, the highest DPPH activity observed in our study (ripe–ethyl acetate extract) reached 57.6 ± 10.37 mmol TE/kg DW (5760 µmol TE/100 g DW), indicating markedly stronger antioxidant potential. Moreover, FRAP values reported by the same authors (96 ± 25 mg TE/100 g DM) were also considerably lower than the TAC values measured in our ethyl acetate extracts using the phosphomolybdenum method (Kamiloglu and Capanoglu, 2015). Therefore, direct numerical comparisons with previous reports could not be made. Nonetheless, it is widely recognized that antioxidant capacity in figs is strongly influenced by phenolic composition, solvent polarity, and the maturity stage of the fruit (Çalışkan and Polat, 2012; Harzallah et al., 2016; Buyuktuncel et al., 2014). In this study, the high TAC values obtained from ripe fig samples extracted with ethyl acetate and acetone may be linked to factors such as changes in fruit composition during ripening and the polarity of the solvents.

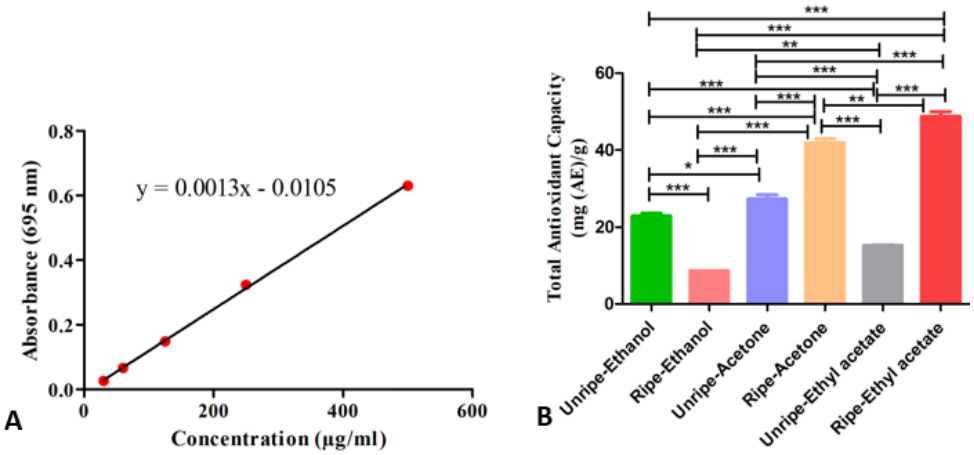

Figure 3. A) Ascorbic acid standard graph. **B)** Total antioxidant capacity (mg AE/g) of unripe and ripe fig extracts obtained using different solvents (ethanol, acetone, and ethyl acetate). The error bars represent the standard deviation (SD) of three independent measurements (*p < 0.05, **p < 0.01, ***p < 0.001).

Antioxidant Activity (DPPH Assay)

The antioxidant activity of fig extracts, as determined by the DPPH radical scavenging method, varied depending on both the extraction solvent and the ripening stage of the fruit. Antioxidant activities were expressed as Trolox equivalents (TE), based on a standard curve generated from Trolox solutions (Figure 4A). In unripe fig samples, antioxidant activity was measured as 19.96 ± 3.32 mmol TE/kg DW for ethanol, 53.9 ± 6.17 mmol TE/kg DW for acetone, and 45.6 ± 0.05 mmol TE/kg DW for ethyl acetate. In ripe fig samples, the values were 6.0 ± 0.59 mmol TE/kg DW (ethanol), 54.5 ± 3.08 mmol TE/kg DW (acetone), and 57.6 ± 10.37 mmol TE/kg DW (ethyl acetate) (Figure 4B and Table 1). Although unripe–ethanol extracts showed significantly higher activity than ripe–ethanol ones (p = 0.1513), no statistically significant differences were detected between unripe and ripe samples in the acetone (p = 0.9559) or ethyl acetate (p = 0.4543) groups. According to statistical evaluation, antioxidant activity was significantly affected by solvent type (p = 0.0019), suggesting that both solvent polarity and fruit ripening stage play a role in modulating the radical scavenging capacity of fig extracts.

A previous study reported DPPH activities of aqueous fig extracts ranging from 1657.04 to 2241.20 mg Trolox/100 g DW (equivalent to 16.57–22.41 mmol TE/kg DW) (Nakilcioğlu and Hışıl, 2013). The values obtained in this study for acetone and ethyl acetate extracts—particularly in ripe samples—exceeded this range, supporting the efficiency of semi-polar solvents in recovering antioxidant compounds (Stalikas, 2007). Notably, ethanol-extracted unripe figs showed higher activity than their ripe counterparts, despite having a lighter color (Lopez-Martinez et al., 2012). This contrasts with findings by Harzallah et al. (2016), who reported higher DPPH activity in dark-colored fig peels, suggesting that pigmentation contributes to antioxidant capacity. Our results, however, imply that color intensity alone does not predict antioxidant potential (Rodríguez et al., 2013). Instead, factors such as phenolic concentration, solvent affinity, tissue integrity, and cultivar-specific traits likely interact to determine extract activity (Slatnar et al., 2011; Li et al., 2013; Pereira et al., 2017).

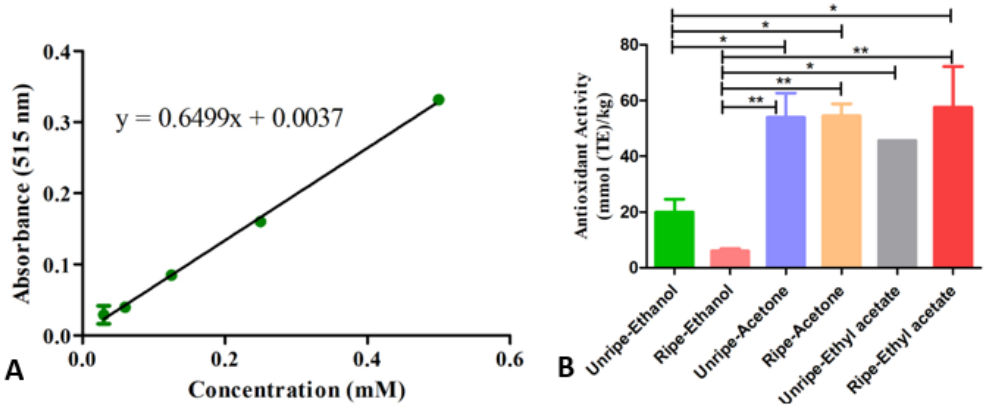

Figure 4. A) Trolox standard graph. **B)** Antioxidant activity (mmol TE/kg) of unripe and ripe fig extracts using different solvents (ethanol, acetone, and ethyl acetate) determined by the DPPH assay. The error bars represent the standard deviation (SD) of three independent measurements (*p < 0.05, **p < 0.01, ***p < 0.001).

Table 1. Total phenolic content (TPC), total antioxidant capacity (TAC), and antioxidant activity (DPPH assay) of unripe and ripe fig (Ficus carica L.) extracts obtained using different solvents.

Solvents	TPC (mg GAE/kg DW)		P1	TAC (mg AE/g DW)		P1	Antioxidant activity (mmol TE/kg DW)		P1
	Unripe Fig	Ripe Fig		Unripe Fig	Ripe Fig		Unripe Fig	Ripe Fig	
Ethanol	1333±49.4^{b}	154±52.2^{b}	0.0387	22.9±0.51^{d}	8.60±0.06^{f}	0.0227	19.9±3.32^{c}	6.00±0.59^{d}	0.1513
Acetone	3680±186^{a}	3976±527^{a}	0.6869	27.3±0.82^{c}	41.9±0.76^{b}	0.0484	53.9±6.17^{a}	54.5±3.08^{a}	0.9559
Ethyl Acetate	595±335^{b}	1220±50.9^{b}	0.3161	15.2±0.11^{e}	48.8±0.87^{a}	0.0166	45.6±0.05^{b}	57.6±10.4^{a}	0.4543
P2	0.0002			< 0.0001			0.0019		

Note: Values are expressed as mean ± standard deviation (n = 3). P1: Statistical comparison between unripe and ripe fig extracts for each solvent, calculated using unpaired t-test with Welch's correction. P2: Overall comparison among all groups using one-way ANOVA followed by Tukey's multiple comparison test. Superscript letters (e.g., ^{a}, ^{b}, ^{c}...) indicate statistically significant differences among all extract groups based on Tukey's test. Groups sharing the same letter are not significantly different ($p > 0.05$).

CONCLUSION

This study demonstrated that both solvent polarity and fruit ripening stage significantly affect the extraction yield, phenolic content, and antioxidant potential of fig extracts. Among the tested solvents, ethanol yielded the highest extraction efficiency, particularly in ripe samples. The highest phenolic content was obtained from ripe figs extracted with acetone, while the greatest antioxidant capacity (TAC) was observed in ripe figs extracted with ethyl acetate. Antioxidant activity measured by the DPPH method was highest in ripe–ethyl acetate extracts. However, the lack of experimental replication in extraction and the use of a single antioxidant assay (DPPH) limit the generalizability of the results. Future studies should incorporate a broader range of antioxidant tests such as ABTS and FRAP, repeated extractions, and explore different fig varieties and plant parts (e.g., peel, leaf) to validate and expand these findings. Overall, these results highlight the importance of optimizing extraction parameters to enhance the recovery of bioactive constituents and support the potential of fig fruits as a valuable natural source of antioxidants.

Declaration of interests

The authors declare that they have no conflict of interest.

Author Contributions

***Zeynep DOĞRU*:** Conceptualization; data curation; formal analysis; investigation; methodology; project administration; software; writing— original draft; writing—review and editing.
Mehmet AKBULUT: Data curation; funding acquisition; investigation; writing—review and editing.
Hüsamettin VATANSEV: Conceptualization; formal analysis; funding acquisition; project administration; writing—review and editing.
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Original Article

Determination of Relationships Between Colour Indices and Colour Parameters in Dried Persimmon Slices

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ABSTRACT

In this study, the effects of different infrared radiation intensity (IP) and air velocity (Av) on color index values and color change indicators of persimmon varieties (Fuyu, Hachiya and Rojo Brillante) were investigated and the relationships between color change indicators and color indexes were determined to define color quality. Drying trials were conducted at 1037, 1210 and 1407 W m^{-2} IP and 1.0, 1.5 and 2.0 m s^{-1} Av. During the drying process, the power of the energy source and air velocity were the factors directly affecting the color index and color change values of persimmon varieties. According to the results obtained, in terms of the change in color indices, the change in browning index (*ΔBI: 9.47*) and yellowness index (*ΔYI: 10.08*) was less in Rojo Brilllante variety compared to other varieties, while the change in whitening index (*ΔWI: 4.61*) was observed more. In color change indicators, total color change (*ΔE*) was lower in Hachiya (*ΔE: 7.36)* and Fuyu (*ΔE: 7.43)* varieties, change in color saturation (*ΔC*: 11.15*) was lower in Rojo Brillante variety and change in hue angle (*ΔH*: 3.47*) was lower in Fuyu variety. Regarding the relationships between color change and color indices, *ΔE - Δa*, ΔBI - ΔYI, Δb* - ΔC** values exhibited similar behavior with each other, while behavioral differences occurred between *ΔH* - Δa*, ΔL* - ΔE* and *ΔE - ΔH**.

Key words: Persimmon, infrared drying, color change, browning index, whitening index, yellowness index

Kurutulan Trabzon Hurması Dilimlerinde Renk İndeksleri ve Renk Parametreleri Arasındaki İlişkiler

ÖZ

Yapılan çalışmada, Trabzon hurması çeşitlerinde (Fuyu, Hachiya ve Rojo Brillante) farklı infrared radyasyon yoğunluğunun (IP) ve hava hızının (Av) renk indeks değerleri ve renk değişim göstergeleri üzerindeki etkileri incelenmiş ve renk kalitesinin tanımlanmasında renk değişim göstergeleri ve renk indeksleri arasındaki ilişkilerin belirlenmesi amaçlanmıştır. Kurutma denemeleri 1037, 1210 ve 1407 W m^{-2} IP'de ve 1.0, 1.5 ve 2.0 m s^{-1} Av'de gerçekleştirilmiştir. Kurutma işlemi sırasında enerji kaynağının gücü ve hava hızı; Trabzon hurması çeşitlerinin renk indeks ve renk değişim değerlerini doğrudan etkileyen faktörler olmuştur. Elde edilen bulgulara göre, renk indekslerindeki değişim bakımından Rojo Brilllante çeşidinde diğer çeşitlere kıyasla kahverengileşme indeksinde değişim (*ΔBI: 9.47*) ve sarılık indeksinde (*ΔYI: 10.08*) değişim daha az olurken, beyazlaşma indeksinde değişim (*ΔWI: 4.61*) daha fazla gözlenmiştir. Renk değişim göstergelerinde, toplam renk değişimi (*ΔE*) Hachiya (*ΔE: 7.36)* ve Fuyu (*ΔE: 7.43)* çeşitlerinde, renk doygunluğundaki değişim (*ΔC*: 11.15*) Rojo Brillante çeşidinde, hue açısındaki değişim (*ΔH*: 3.47*) ise Fuyu çeşidinde daha düşük olmuştur. Renk değişimi ve renk indeksleri arasındaki ilişkilere yönelik değerlendirildiğinde *ΔE - Δa*, ΔBI - ΔYI, Δb* - ΔC** değerleri birbirleriyle benzer davranış sergilerken, *ΔH* - Δa*, ΔL* - ΔE* ve *ΔE - ΔH** arasında davranışsal farklılıklar meydana gelmiştir.

Anahtar kelimeler: Trabzon hurması, infrared kurutma, renk değişimi, kahverengileşme indeksi, beyazlaşma indeksi, sarılık indeksi

INTRODUCTION

Persimmon (*Diospyros kaki L.*), a member of the Ebenaceae family, is mainly produced in China, Korea and Japan (Vivek et al., 2021). It is a type of fruit whose consumption and cultivation is increasing day by day, especially in our country and in the world. The fruits are oblong and there are also species with different shapes and colors (Celik and Ercisli, 2008). Since persimmon is rich in bioactive compounds with antioxidant properties such as phenolics, flavonoids, carotenoids, ascorbic acid and tannins, it also has many health benefits (Tosya et al., 2024). Treating cardiovascular and digestive system diseases, preventing cancer diseases, lowering blood pressure and cholesterol are just a few of them (Wei et al., 2022). Persimmon is a rich resource in high demand for its flavor, nutritional content and medicinal value. However, being a seasonal fruit limits access to the product throughout the year due to its short-term consumption (Lim and Eom, 2022). For this reason, drying is one of the practical methods to prolong the duration of the fruit without spoilage and to minimize quality losses in the final product (Bölek, 2020).

Persimmon is a fruit that stands out with its unique color and is expected to maintain its attractiveness and quality after drying. Color is one of the parameters looked at in terms of quality in foods and the first idea about the product is given by looking at the color of the product. If a desired color cannot be observed by the consumer, the food will receive a bad score, no matter how good the nutritional content, taste and aroma of the food (Doymaz and Aktaş, 2018). Therefore, manufacturers also need to carefully consider the color characteristics of the product and the changes that occur during heat treatment (Bahçeci and Acar, 2020). Some problems are encountered as a result of drying persimmon, which has high moisture and sugar content, with traditional methods, especially at high temperatures. Negativities such as the fact that the drying process takes place over a long period of time and accordingly, the product remains under the influence of heat energy for a long time, resulting in significant differences in product color. For this reason, drying processes with short drying time and high energy efficiency are desired to prevent negative effects on product quality. Due to these features, infrared drying has become a preferred technique in recent years (Sakare et al., 2020).

Color indicators such as ΔH^*, ΔC^* and ΔE are used to evaluate color changes in the product. The ΔE value alone is not a sufficient indicator to fully describe the color changes occurring in the product. In this respect, in order to identify which color parameters are responsible for the color change, L^*, a^*, b^* values as well as other indicators of color change should be taken into account (Keskin et al., 2019). Soysal et al. (2005) stated in their study that ΔE^* and ΔC^* deviation values used for comparison with other chromatic aberration values are not a good indicator to identify color changes, and that different colors may have the same chroma value. It also stated that ΔH^* is a chromatic aberration model that includes all color properties and is also used to describe the direction of color change. Color index values also offer reliable and multidimensional approaches to assessing color-related quality attributes of products. Color indices are used in the analysis of quality changes as a result of the application of heat treatments such as hot air flow, microwave, freezing, radio frequency, infrared, etc. to products, in determining the conformity of food quality to standards, as well as in the quality control of fresh and processed foods. Color indices are used in the analysis of quality changes that occur as a result of applying heat treatments such as hot air flow, microwave, freezing, radio frequency, infrared, etc. to products, in determining the conformity of food quality to standards, as well as in quality control of fresh and processed foods. The complexity between colors and color indices in products can cause some problems in production and quality control processes. Natural discoloration of the product does not always indicate product spoilage, but is related to the natural processes of the product and can occur as a result of oxidation and enzymatic reactions. In previous studies, only color indices were evaluated (Vivek et al., 2021; Karaman et al., 2014; Yildiz et al., 2024; Yılmaz, 2022). However, in this case, interpreting only color indices can lead to incorrect quality assessments (Francis, 1995; Pathare et al., 2013). In this direction, studies to determine the relationships between color change indicators and color indices will help to eliminate the complexity between these two concepts. In this study, it was aimed to investigate the changes in color values and color indices of persimmon varieties during drying with infrared energy and to define the relationships between them.

MATERIALS AND METHODS

Fuyu, Hachiya and Rojo Brillante persimmon varieties were used in the study and obtained from a local producer in Çanakkale. The samples were kept in the refrigerator at +4 °C, taken to the laboratory and allowed to reach room temperature before the drying experiments started. For the initial moisture content of persimmon, the samples were kept in an oven at 105 °C for 24 hours and the initial moisture content was determined as 82.33% (w.b.).

Drying Experiments

For the drying experiments, a laboratory-scale infrared drying apparatus equipped with an emitter with an infrared medium wavelength (2.4-2.7 µm) and adjustable radiation intensity**,** designed within a TÜBİTAK project, was used (Kocabiyik et al., 2014). Drying experiments were carried out at infrared radiation intensities (IP) of 1037, 1210 and 1407 W m^{-2} and air velocities (Av) of 1.0, 1.5 and 2.0 m s^{-1}. Approximately 250 g of samples were used in each experiment, the inlet air temperature was measured at 25 ± 2 °C during the drying process and no heating was applied. The dryer was idle for approximately 10 minutes before each experiment to ensure the required conditions in the dryer. The samples were placed in a thin layer on a teflon drying tray (400 x 250 mm) and 10 slices were selected and numbered to determine the color values before and after drying (Or et al., 2024). The samples were washed and peeled before the drying trials and cut into 5 mm slices using a household slicer. The mass change in the samples was measured using Precisa XB 3200C precision balance and Balint software with an accuracy of 0.01 g at 3 min intervals and transferred to the computer, and the drying process was finalized at a target moisture content of 25% (w.b.).

Color Parameters and Change Indicators

Color measurements of the selected and numbered slices were performed with a Minolta CR-400 colorimeter (Minolta Co., Osaka, Japan). The instrument was calibrated with a white reference plate. Color measurements were performed in CIE *Lab** color space, where *L** (brightness), *a** (redness/greenness) and *b** (yellowness/blueness) values of the samples were read according to the color coordinate system. As the *L** value approaches 0, it characterizes the darkness of the color, and as it approaches 100, it characterizes the brightness. The vividness or pastelness of the color of the product is defined by chroma (*C*), with values close to 0 representing pastel tones and values close to 100 representing vivid tones. The change in color saturation (*ΔC**) refers to the rate at which the vividness of the product color changes and is given in the following equations respectively.

$$C = \sqrt{(a^{*2} + b^{*2})} \quad \text{Equation (1)}$$

$$\Delta C^* = C_d^* - C_f^* \quad \text{Equation (2)}$$

Where; *f* and *d* are the color parameters of fresh and dry samples respectively.

The color angle (*h°*) gives the angle value corresponding to the base color of the product. 0° corresponds to the *"+a*"* axis (red), 90° to the *"+b*"* axis (yellow), 180° to the "*-a**" axis (green) and 270° to the "*-b**" axis (blue). *ΔH** defines the direction of color change. The equations defining *h°* and *ΔH** are given below, respectively.

$$h^\circ = \tan^{-1} b^*/a^* \quad \text{Equation (3)}$$

$$\Delta H^* = H_d^* - H_f^* \quad \text{Equation (4)}$$

Where; *f* and *d* are the respective color parameters of fresh and dry samples.

Total color change (*ΔE**) is a value that numerically expresses how far the product color has moved away from the reference point in cases where color change is considered during the drying process and is calculated with the help of the following equation.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} = \sqrt{\left(L_f^* - L_d^*\right)^2 + \left(a_f^* - a_d^*\right)^2 + \left(b_f^* - b_d^*\right)^2} \quad \text{Equation (5)}$$

Where; *f* is the relevant color parameters of fresh samples and *d* is the relevant color parameters of dried samples.

Browning (BI), whitening (WI) and yellowness (YI) indices are other important indicator values that can be used to describe the change in color properties of samples after drying. *BI*, *WI* and *YI* indices were determined with the help of the equations given below.

$$x = a^* + (1.75\ x\ L^*)/\left[(5.645\ x\ L^*) + \left(a^* - (3.012\ x\ b^*)\right)\right] \quad \text{Equation (6)}$$

$$BI = \left[100\ (\mathrm{x} - 0.31)\right] / 0.17 \quad \text{Equation (7)}$$

$$WI = 100 - \sqrt{[(100 - L^*)^2 + (a^*)^2 + (b^*)^2]} \quad \text{Equation (8)}$$

$$YI = 142.86\, b^* / L^* \quad \text{Equation (9)}$$

Statistical Analysis

The effects of cultivar, infrared radiation intensity (IP) and air velocity (Av) as independent variables on color indicator values *ΔE*, *ΔC**, *ΔH**, *ΔBI*, *ΔWI* and *ΔYI* were determined by ANOVA test at 5% significance level using Minitab R21.4 statistical software (StatSoft, Inc., Tulsa OK, USA). Differences between averages were determined by Tukey test at 5% confidence level. The relationships between color indicators were identified by Principal Component Analysis and individual relationships were determined by correlation analysis. OriginPro 2024 (OriginLab Corporation, Northampton, MA, USA) was used for Principal Component Analysis.

RESULTS AND DISCUSSION

The color change (*ΔE*) of dried persimmon samples was in the range of 6.53-13.96 for Fuyu variety, 13.65-21.01 for Hachiya and 7.64-16.34 for Rojo Brillante. (Figure 1). The highest and lowest *ΔE* was recorded for Hachiya and Fuyu varieties at 1407 W m^{-2} IP and 2.0 m s^{-1} Av, respectively. Variety x IP, IP x Av and variety x IP x Av factor interactions had a statistically significant effect on *ΔE* ($p<0.05$).

In the study conducted using continuous (300, 400 and 500 W) and intermittent (20 s on-40 s off and 30 s on-30 s off) infrared drying of persimmon slices, *ΔE* values were found to be in the range of 30.89-31.07 and 18.33-29.28 for continuous and intermittent drying, respectively (Polat et al., 2024). In the study where persimmon was dried convectively (45-65 ℃), *ΔE* values were reported to be in the range of 9.2-18.9. It was also stated that at the highest temperature value of 65°C, the fruit was able to maintain its unique color (Senadeera et al., 2020).

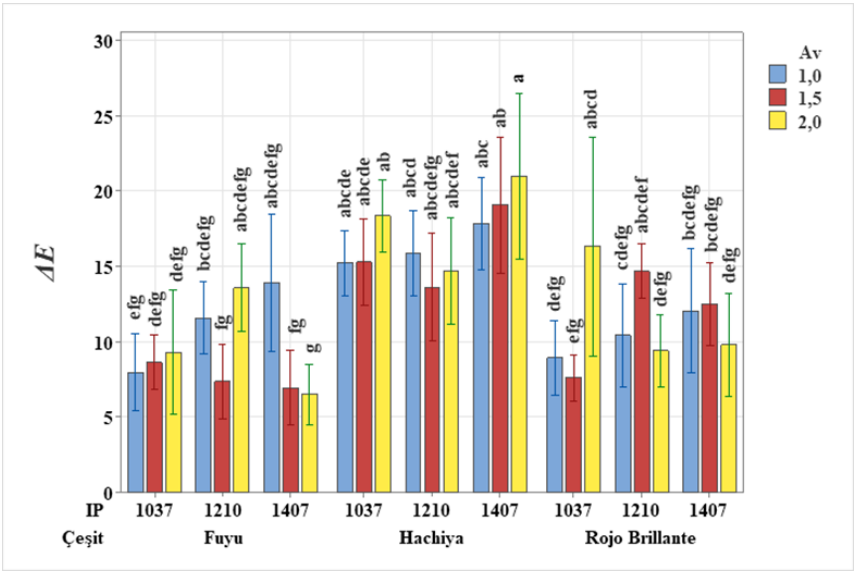

Figure 1. Total color change

The variation of color saturation change (*ΔC**) according to variety, IP and Av is given in Figure 2. In terms of varieties, *ΔC** values ranged between -9.84 and 5.51 for Fuyu, -8.46 and 4.49 for Hachiya, and -10.5 and 0.65 for Rojo Brillante. Rojo Brillante variety had the highest *ΔC** value with 1.5 m s^{-1} at 1210 W m^{-2} IP, while Rojo Brillante variety had the lowest *ΔC** value with 1.0 m s^{-1} at 1407 W m^{-2} IP. While the effect of variety and IP alone on *ΔC** was insignificant, the effect of Av on *ΔC** was significant. The effects of variety x IP, variety x Av and all factor interactions on *ΔC** were statistically significant ($p<0.05$).

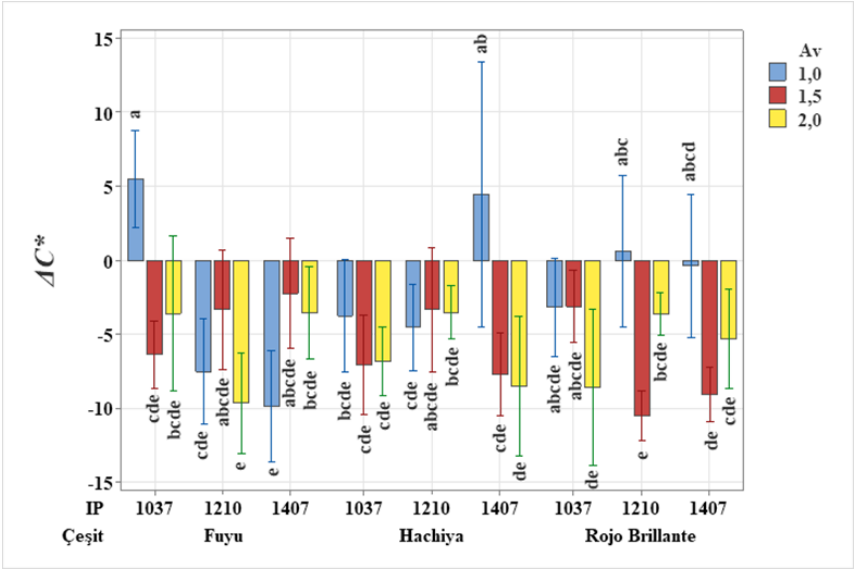

Figure 2. Color saturation change

The change in hue angle (*ΔH**) in persimmon samples depending on drying conditions is given in Figure 3. In terms of varieties, *ΔH** values varied between 1.76 and 5.23 for Fuyu, -1.24 and 15.34 for Hachiya, and 1.19 and 10.51 for Rojo Brillante. The highest and lowest *ΔH** change was realized at 1407 W m^{-2} IP at 1.0 m s^{-1} Av and 1210 W m^{-2} IP at 1.0 m s^{-1} Av in Hachiya variety, respectively. In parallel with this situation, the highest change was observed in Hachiya variety. Among the factors, the effect of variety, IP and Av alone on hue angle change was significant. In addition, variety x Av, IP x Av and all factor interactions had a significant effect on hue angle change ($p<0.05$).

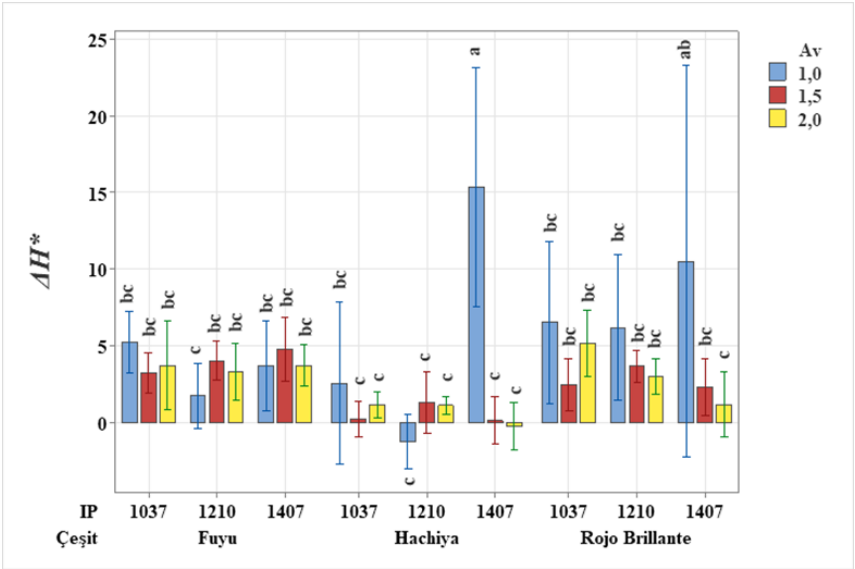

Figure 3. Hue angle change

The change in browning index (*ΔBI*) of the samples before and after drying is given in Figure 4. Browning index (*BI*) values were in the range of 115.52- 148.97 for Fuyu variety, 80.25-113.13 for Hachiya and 72.59-82.06 for Rojo Brillante. The highest *ΔBI* occurred at 1407 W m^{-2} IP and 1.0 m s^{-1} air velocity in Hachiya variety, while the lowest *ΔBI* occurred at 1210 W m^{-2} IP and 2.0 m s^{-1} air velocity in Rojo Brillante variety. Among the factors, variety alone, IP and Av had a statistically significant effect on *ΔBI*, while the effect of all factor interactions on *ΔBI* was insignificant ($p>0.05$).

In the study in which persimmons with different slice thicknesses were convectively dried using different temperatures (50, 60 and 70 °C) and air velocities (0.5, 1.0 and 1.5 m s^{-1}), it was concluded that *BI* values tended to decrease with increasing air velocity. This may be due to the decrease in drying times with the increase in air velocity and consequently less brown pigment formation (Vivek et al., 2021). Karaman et al. (2014) dried

persimmon by freeze, vacuum and hot air drying methods and emphasized that the highest *BI* value was in vacuum drying (2.32) due to the long drying time compared to other drying methods.

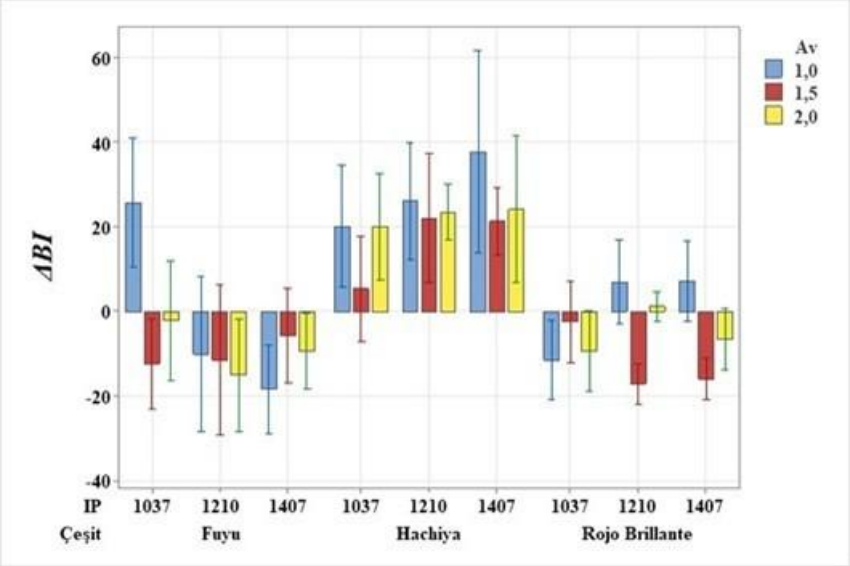

Figure 4. Change in browning index

The change in whitening index (*ΔWI*) in persimmon samples before and after drying depending on the drying conditions is shown in Figure 5. Whitening index (*WI*) values were in the range of 37.03-41.40 for Fuyu, 43.04-47.32 for Hachiya and 47.97-52.58 for Rojo Brillante. In the graph, the differences between varieties are clearly revealed. Lower whitening index change was realized in Fuyu variety compared to other varieties. In Fuyu variety, *ΔWI* was lowest at 1210 W m^{-2} IP and 1.0 m s^{-1} air velocity. In this drying condition, it can be said that a large amount of browning occurred in the product. The effect of variety and IP individually on *ΔWI* was significant ($p<0.05$), but the effect of Av alone was not significant.

Yildiz et al. (2024) found that the *WI* values of persimmon slices (10 mm) varied between 29.26-32.27 in convective drying method. Yılmaz (2022) conducted a study on persimmon with convective, microwave and combined drying method combining these methods and observed more change in the whitening index in the combined microwave-convective drying method. It was also reported that the whitening index increased with increasing temperatures in samples dried by convective drying.

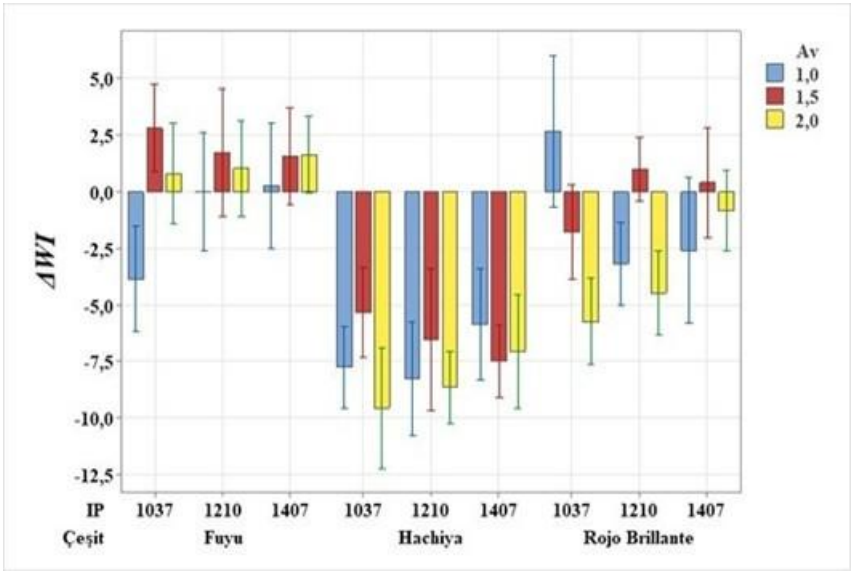

Figure 5. Change in whitening index

The yellowness index (*YI*) of dried persimmon samples varied between 93.66-110.52 for Fuyu variety, 68.31-96.97 for Hachiya and 69.14-79.22 for Rojo Brillante. (Figure 6). While the lowest *ΔYI* occurred at 1407 W

m^{-2} and 1.5 m s^{-1} air velocity in Fuyu variety, the highest *ΔYI* occurred at 1407 W m^{-2} and 1.0 m s^{-1} air velocity in Hachiya variety. When a general evaluation is made, it is seen that the change in the yellowness index of Rojo Brillante variety is realized at a low level. Variety, IP and Av variables individually and their interactions (Variety x Av, IP x Av, Variety x IP x Av, Variety x IP x Av) had a statistically significant effect on yellowness index ($p<0.05$).

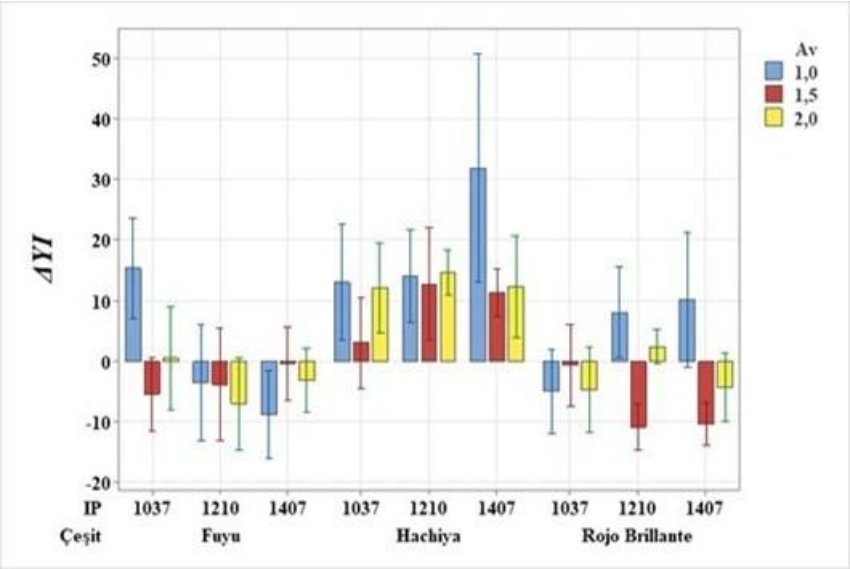

Figure 6. Change in yelllowness index

When the negative and positive correlations between the color change indicators and color indices of persimmon were examined, a strong positive correlation was found between *ΔC* - Δb** (r:0.995; $p<0.05$), *ΔYI - ΔBI* (r:0.965; $p<0.05$) and *ΔYI - ΔC** (r:0.756; $p<0.05$). A strong negative correlation was found between *ΔWI - ΔBI* (r:-0.783; $p<0.05$), *ΔE - ΔL** (r:-0.752; $p<0.05$) and *ΔH* - Δa** (r:-0.735; $p<0.05$) (Figure 7 and Table 1).

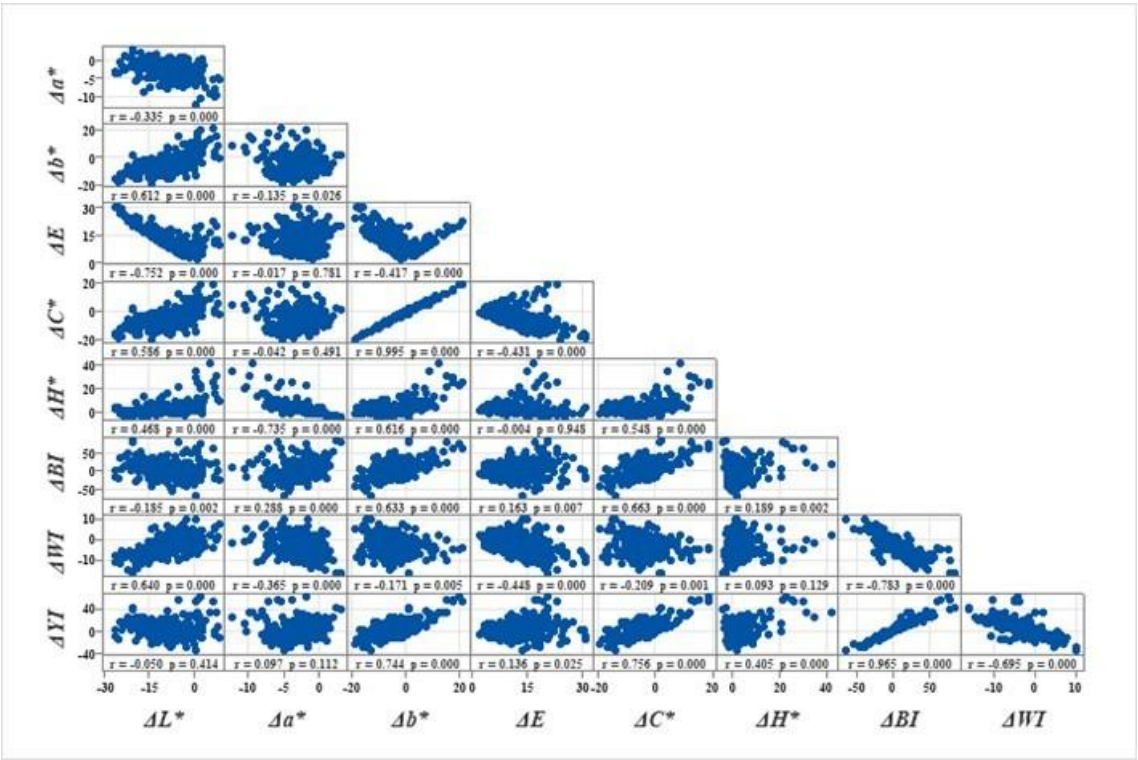

Figure 7. Correlations between color indices and color change indicators

Table 1. Correlation equations for color indices and color change indicators

Correlation equation	R^2 *value*
$\Delta E = 7.448 - 0.6277\ \Delta L^*$	$R^2 = 0.5658$
$\Delta H^* = -1.515 - 1.848\ \Delta a^*$	$R^2 = 0.5407$
$\Delta C^* = -0.8600 + 0.93858\ \Delta b^*$	$R^2 = 0.9898$
$\Delta YI = 11.375 + 1.7129\ \Delta C^*$	$R^2 = 0.5721$
$\Delta WI = -2.174 - 0.16617\ \Delta BI$	$R^2 = 0.6133$
$\Delta YI = 1.369 + 0.6062\ \Delta BI$	$R^2 = 0.9318$

The interactions between the studied color parameters and color change indicators in dried persimmon samples were analyzed using principal component analysis (PCA). Principal Component Analysis (PCA) was used to show the positive or negative positions of the interactions between the parameters under study. As a result of the Principal Component Analysis of the color characteristics of dried products, the first two principal components were found to have eigenvalues above 1 and explained more than 81% of the total variation (Figure 8 and Table 2).

The first two components explained 81.76% variance as indicated in Table 2 and Figure 8. When the contribution of each color feature to the principal components is examined, *ΔL**, *Δa**, *ΔE*, *ΔBI*, *ΔWI* and *ΔYI* contributed to principal component 1, while *Δb**, *ΔC** and *ΔH** contributed to the second principal component. The results obtained in the principal components analysis are in line with the correlation analysis.

When all features were analyzed, *ΔE*, *Δa**, *ΔBI*, *ΔYI*, *Δb**, *ΔC** were located in the positive direction of the center point in the PC1 component, while *ΔH**, *ΔL**, *ΔWI* were located in the negative direction of the center point (Figure 9). The fact that the features are located in different directions from the center point has created a behavioral difference between these features. Likewise, *ΔE - ΔL** were located in symmetrical positions on the axes. *ΔE - Δa**, *ΔBI - ΔYI* and *Δb* - ΔC** showed similar behavioral effects, while *ΔH* - Δa** showed an opposite effect.

In our study, the yellowness index (*ΔYI*) had a similar effect with the browning index (*ΔBI*) and an opposite effect with the whitening index (*ΔWI*). A similar effect was observed in drying trials on the Rojo Brillante variety. Rojo Brilllante variety showed lower *ΔBI*, *ΔYI* and higher *ΔWI* compared to Fuyu and Hachiya varieties.

When the dependent changes of color change indicators and color indices were examined, a difference in behavioral tendency between *ΔE* and *ΔH** was revealed. This trend between color changes in our study was similar to the trend between *ΔE* and *ΔH** values obtained for convectively dried Tito carrot variety in the study conducted by Markowski et al. (2006).

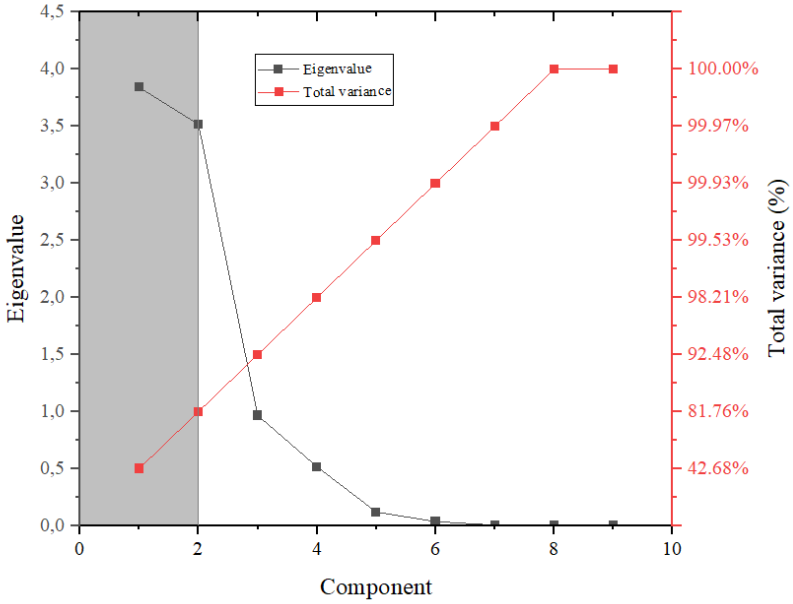

Figure 8. Change of eigenvalue and variance depending on the component

Table 2. Eigenvectors of each principal component for all analyzed features

Feature	TB1	TB2
*ΔL**	**-0.36752**	0.33071
*Δa**	**0.38878**	-0.16023
*Δb**	0.06481	**0.52205**
ΔE	**0.23397**	-0.22137
*ΔC**	0.10023	**0.5097**
*ΔH**	-0.1158	**0.40554**
ΔBI	**0.46556**	0.19691
ΔWI	**-0.48895**	0.02523
ΔYI	**0.41902**	0.28241
Eigenvalue	3.84	3.51
Variance explained (%)	42.68	39.08
Total variance (%)	42.68	81.76

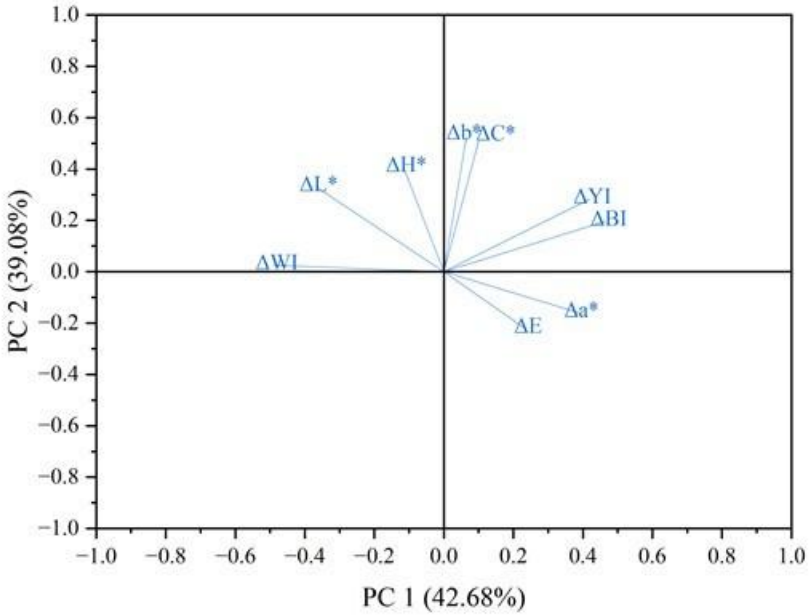

Figure 9. Principal component analysis (PCA) of color change indicators and color indices

CONCLUSION

In this study, the effects of three different infrared radiation intensities and air velocity (IP) on color index values and color change indicators of persimmon varieties were investigated. It is also aimed to reveal the relationships between color change indicators and color indices in defining color quality. In line with the results obtained, when the changes in color indices were examined, lower *ΔBI, ΔYI* and higher *ΔWI* occurred in Rojo Brilllante variety compared to other varieties. In the color change indicators, the total color change (*ΔE*) was lower in Hachiya and Fuyu varieties, the change in color saturation (*ΔC**) was lower in Rojo Brillante variety and the change in hue angle (*ΔH**) was lower in Fuyu variety. When the relationships between color change and color indices were evaluated, it was determined that *ΔE - Δa*, ΔBI - ΔYI, Δb* - ΔC** values exhibited similar behavior with each other, while behavioral differences occurred between *ΔH* - Δa**, *ΔL* - ΔE* and *ΔE - ΔH**. This study provides important data that can be used in quality classification and control processes of fresh and processed foods to reduce confusion between color and color indices.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Araştırma Makalesi

Household Level Analysis of Rural-to-Urban Migration in Türkiye

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ABSTRACT

This study employs micro-scale field research to explore the migration tendencies of the rural population in Türkiye, their attitudes toward agriculture, the structural characteristics of agricultural enterprises, and potential future dynamics. It also aims to examine the link between rural residents and agricultural activity. Data were collected through surveys conducted in 2,398 households across 224 villages/neighborhoods in 27 provinces. Findings indicate that approximately 67% of these locations are characterized as “out-migration areas.” The trend is especially pronounced in the Middle East (94.4%) and Central North (92.3%) regions, whereas the Mediterranean region (55.6%) exhibits a relatively higher rate of in-migration. Despite these migration trends, 79.7% of household heads reported no intention to leave their village or neighborhood, whereas 16.7% expressed a desire to migrate. However, many household heads stated that their children are more likely to consider migration. The primary motivation for those wishing to relocate is low income. These individuals typically prefer to move to the provincial or district centers and intend to do so with their entire families. Conversely, those choosing to remain cited reasons such as land ownership responsibilities, the high cost of living in urban areas, and a strong emotional attachment to rural life. The results of this study provide critical insights into the underlying drivers and outcomes of rural-to-urban migration. They offer valuable guidance for policymakers aiming to sustain agricultural production and mitigate migration through targeted, realistic strategies.

Keywords: Rural, Rural Migration, Household, Agriculture

Türkiye’de Kırsaldan Kente Göçlerin Hanehalkı Düzeyinde Analizi

ÖZ

Bu çalışmada, kırsal nüfusun göç eğilimleri, tarıma bakış açıları, tarımsal işletmelerin yapısı ve gelecekteki muhtemel durumlarını belirlemek, kırsalda yaşayan nüfus ve tarım arasındaki ilişkiyi tespit etmek için mikro ölçekte saha çalışmaları yapılmıştır. Saha çalışmalarında veri toplama tekniği olarak Türkiye’de 27 ilde 224 köy/mahalle ve buralarda yaşayan 2398 hane incelenmiştir. Köy/mahallelerin göç durumlarına yönelik yapılan incelemelerin sonuçlarına göre Türkiye genelinde %67 oranında “göç veren bir köy/mahalle” olgusunun öne çıktığı söylenebilir. Özellikle Orta Doğu (%94,4) ve Orta Kuzey (%92,3) bölgelerindeki köy/mahallelerin yüksek oranda göç veren köy/mahalle olduğu buna karşın Akdeniz Bölgesindeki köy/mahallelerin (%55,6) göç alan köy/mahalle olduğu belirlenmiştir. Diğer taraftan bu köy/mahallelerde yaşayan hane reislerinin genel olarak %79,7’sinin köy/mahallelerinden göç etme isteği bulunmazken %16,7’sinin göç etme isteği olduğu tespit edilmiştir. Hane reisleri göç etme niyetinin çocuklarında var olduğunu ifade etmişlerdir. Daha çok gelir yetersizliği bahanesiyle göç etmek isteyen hane reisleri göç etmek istedikleri yerler için genel olarak bağlı bulundukları il/ilçe merkezini tercih etmekte ve ailesinin tamamı ile birlikte göç etmek istemektedirler. Bölgelerinden göç etmek

istemeyen hane reisleri ilgilenmesi gereken arazilerinin varlığı, şehirde geçinmenin zor olacağı, köy/mahalle hayatını vazgeçemeyecek seviyede sevdiği gibi sebepler ileri sürmektedir. Çalışma sonuçlarının kırsaldan kente göçün olası nedenleri ve sonuçlarını ortaya koyması bakımından önemli olduğu ve tarımsal üretimin devamlılığının sağlanması ve göçlerin makul düzeyde önüne geçilebilmesi anlamında politika yapıcılara ışık tutacağı söylenebilir.

Anahtar kelimeler : Kırsal, Kırsal Göç, Hane Halkı,Tarım

INTRODUCTION

Rural-to-urban migration has historically played a critical role in shaping demographic dynamics, often resulting in notable population declines in rural settlements and giving rise to significant social, cultural, and economic shifts. Villages, traditionally seen as hubs of agricultural production, have also served as key residential zones that host a substantial segment of the national population. However, the persistent migration of educated, young, and economically active individuals signals a long-term disengagement from the agricultural sector posing potential risks to the future vitality and structure of agricultural entrepreneurship. In this context, preserving the rural workforce and encouraging specialization in agricultural occupations is essential for ensuring rural prosperity, sustaining agricultural productivity, and supporting sectoral resilience.

Extensive scholarly research has investigated the causes and consequences of migration, particularly focusing on internal migration dynamics. A considerable body of work has addressed the interprovincial disparities in variables such as population size, income levels, geographic distance, education, and wages (Gawande et al., 2000; Huarez, 2000; Aroca and Hewings, 2002; Devillanova and Garcia-Fortes, 2004; Miguel et al., 2006; Ederveen et al., 2007). Other studies have examined the influence of age, wealth, inflation, employment, and security concerns (e.g., terrorism) on migration decisions (Pazarlıoğlu, 2007; Çatalbaş and Yarar, 2015; Mueller et al., 2018). Furthermore, specific attention has been directed toward rural migration drivers such as income variability, land ownership, education access, healthcare availability, land fragmentation, labor force dynamics, disease prevalence, mortality rates, crime levels, and proximity to urban centers (Shrestha et al., 1993; Butzer et al., 2002; Aşkın et al., 2013; Oğuz et al., 2016).

In the Turkish context, rural migration has been examined within both historical and economic frameworks. Since the 1950s—parallel to industrialization efforts—rural-to-urban migration has been perceived as a facilitator of national development (Yavuz et al., 2004). Particularly after the 1980s, significant migration flows have been observed, influenced by nationwide socio-economic transformations (İçduygu et al., 1998; Çınar and Lordoğlu, 2011; Aşkın et al., 2013). Several studies highlight how the gradual withdrawal of government support for agriculture, the imposition of production quotas, and increasing input costs have destabilized rural economies, driving households toward cities in search of financial stability (Lordoğlu, 2006; Karabulut and Polat, 2007).

For example, Bostan (2017) identified a combination of inadequate healthcare and education services, limited social infrastructure, severe climate conditions, and urban employment prospects as key migration motivators in the eastern provinces of Ağrı, Kars, Iğdır, and Ardahan. Similarly, research conducted in the Emirdağ district of Afyon revealed that rural depopulation—particularly pronounced after the 1960s—has led to widespread village abandonment, with the remaining populations often composed of elderly individuals, thus impeding agricultural continuity (Yakar and Yazıcı, 2009). In a study conducted in Van, Zırhlıoğlu (2010) found that persistent migration from rural areas was largely driven by regional income disparities, unemployment, and security concerns, especially in eastern Anatolia, further underscoring migration as a critical challenge for the agricultural sector.

Against this backdrop, the present study seeks to explore the rural population's migration tendencies, their views on agriculture, the structure of agricultural enterprises, and potential future trajectories. To this end, micro-scale field research was carried out to examine the relationship between rural populations and agricultural activity. The fieldwork involved data collection from 2398 households across 224 villages or neighborhoods within 27 provinces throughout Turkey.

MATERIALS AND METHODS

This study utilized Turkey’s nine agricultural production regions, as designated by the Food and Agriculture Organization to construct a representative sampling framework (Anonymous, 2018). Initially, three provinces were selected from each agricultural region to reflect the diverse characteristics of the area. The selection criteria included geographical diversity, the average net migration rates between 2008 and 2020 (13-

year average), and relevant economic and temporal considerations (see Table 1). As a result, the study encompassed 27 provinces across the country.

In selecting provinces, care was taken to include those with varying migration patterns provinces that were major sources of out-migration, those receiving high levels of in-migration, and those with moderate migration flows. This strategy allowed for a more balanced and inclusive assessment of migration tendencies by incorporating regions with differing demographic dynamics.

Table 1. Provinces surveyed

Regions	Provinces and Net Migration Rates (The average net migration rates between 2008 and 2020)
Central North	Yozgat (-18.03), Çankırı 1.71), Eskişehir (8.67)
Aegean	Manisa (0.52), Isparta (1.19), Muğla (9.64)
Marmara and Thrace	Edirne (0.30), Sakarya (5.04), Tekirdağ (18.80)
Mediterranean	Kilis (-5.86), Mersin (-0.59), Antalya (10.88)
North East	Ağrı (-23.68), Artvin (-3.08), Erzincan (-0.26)
South East	Muş (-21.46), Şanlıurfa (-6,01), Batman (-3.06)
Black Sea	Zonguldak (-8.63), Gümüşhane (-0.44), Sinop (2.92),
Middle East	Adıyaman (-9.82), Tokat (-8,69), Tunceli (0.70)
Central South	Niğde (-5.10), Konya (-1.52), Kayseri (1.58)

Sources: Calculated by researchers

The target population for the field study was defined by examining interprovincial migration trends across age groups to identify segments most likely to migrate. According to Anonymous (2019), the total rural/neighborhood population across the selected provinces amounted to 1349610 individuals. The sample size was calculated using the following formula from Çiçek and Erkan (1996):

$$n=N(pq) / (N-1)D^2+(pq) \qquad (1)$$

Where:

n = required sample size,
N = total population size,
D = allowable margin of error (calculated as d/t, with d = 2% and t = 95% confidence level),
p = probability of an individual remaining in agriculture (assumed to be 0.5),
q = 1 − p.

Based on this formula, the required sample size was determined to be 2398 individuals. This sample was proportionally distributed across the nine agricultural regions and their corresponding 27 provinces. Accordingly, fieldwork was conducted in 224 rural settlements (villages/neighborhoods) selected from these areas. The geographical focus of the research included rural areas located outside urban centers, encompassing rural neighborhoods within the jurisdiction of metropolitan municipalities. The locations for data collection were identified with assistance from provincial and district agricultural and forestry directorates. Field visits were organized in consultation with local authorities, such as village headmen or other informed community members, to gather preliminary information about the settlement's general structure and migration patterns. In addition to this contextual data, structured face-to-face interviews were conducted with household heads (owners of agricultural enterprises), both male and female. These interviews aimed to collect detailed information on agricultural production structures, including land holdings, livestock numbers, and annual income levels. Participants were also asked about their migration intentions and challenges related to agricultural life, as well as their proposed solutions. The data obtained from 224 village-level interviews and 2,398 household surveys were analyzed separately. Household data were evaluated using descriptive statistics presented in tables and graphs, including percentage distributions and frequency analyses. With the data obtained from a total of 2,622 surveys, many characteristics of households living in rural areas in Türkiye, such as their living standards, socio-economic and demographic characteristics, and agricultural business structures, have been revealed. In the light of all this information, the main subject of the study, the migration trends of households from rural areas, have been examined in all aspects. The findings obtained in the study have been presented with statistics on the scale of all of Türkiye and by region. In this sense, comparative evaluations were made by calculating frequencies and

percentages for both Türkiye and regional averages. Frequency and percentage statistics are presented with tables and colored figures.

RESULTS AND DISCUSSION

Infrastructure status, education, and health services in villages/ neighborhoods

The study collected data regarding the infrastructure facilities of the surveyed villages and neighborhoods. A general observation reveals that most settlements are connected to main roads. However, approximately 10% of the villages/neighborhoods located in the Northeastern, Southeastern, and Central Eastern regions were found to lack proper main road access (Figure 1). In terms of potable water supply, a notable deficiency was identified in the Northeastern and Southeastern regions, where 20–23% of the villages/neighborhoods do not have access to a drinking water network. In contrast, villages in other regions are largely equipped with such infrastructure (Figure 2). When it comes to sanitation, around one-third of the surveyed settlements lack a sewage system. The absence of this infrastructure is most pronounced in the Mediterranean region (70.4%), followed by the Marmara and Thrace region (50.0%). In contrast, regions such as Central East (94.4%), Central North (84.6%), and Southeast (83.3%) demonstrate comparatively better development in sewage system availability (Figure 3).

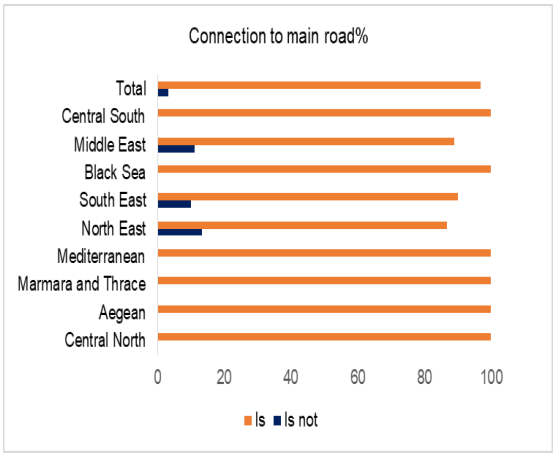

Figure 1. Connection status to the main road

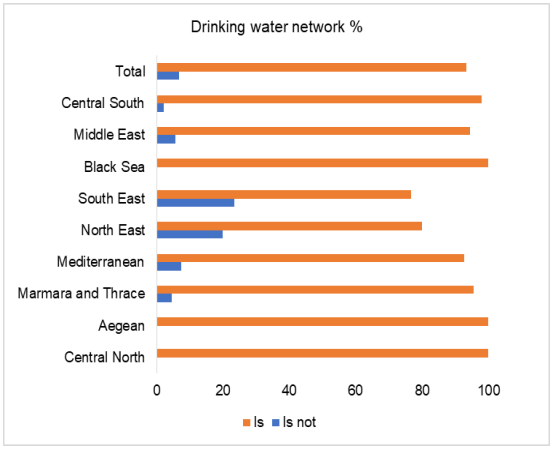

Figure 2. Drinking water network status

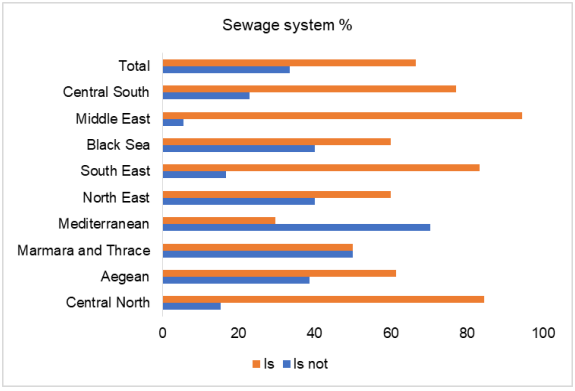

Figure 3. Existence of sewerage system

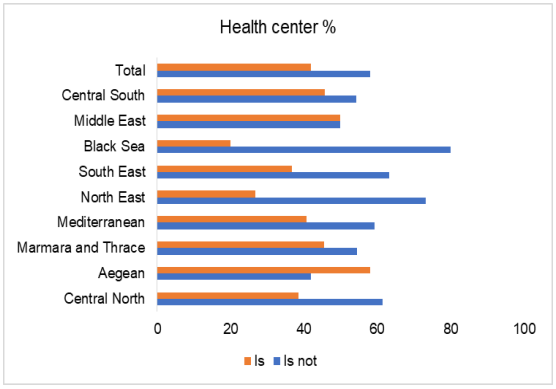

Figure 4. Existence of a health center

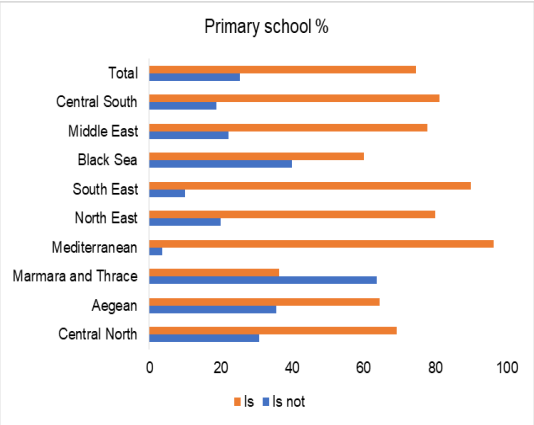

Figure 5. Existence of primary school

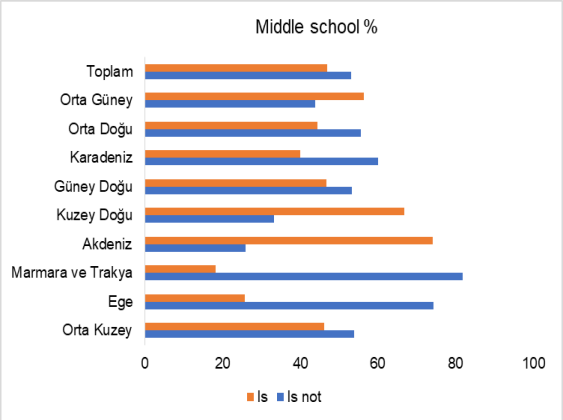

Figure 6. Existence of middle school

The analysis revealed that 58% of the surveyed villages and neighborhoods lack a local healthcare facility. In locations where such facilities are present, they typically operate under the Ministry of Health's family medicine model (Figure 4). However, in most rural settlements excluding larger towns that were temporarily granted neighborhood status under metropolitan municipality legislation there are no fully functioning health centers or family health centers operating on a daily basis. Family health centers in rural areas mainly provide basic medical examinations and conduct simple laboratory tests. As part of the family medicine system, healthcare professionals deliver mobile health services on specific days of the week to patients who are too ill or isolated to travel to centralized facilities. These mobile units are designed to serve remote or underserved communities including villages, hamlets, and outlying neighborhoods and are implemented in line with planned schedules that consider geographic, climatic, and transportation factors. According to the official regulation (Official Gazette, 2010), the duration of healthcare service provided per 100 people in a rural area must not be less than two hours per month, excluding travel time. Mobile healthcare visits are required at least once a month for settlements with populations up to 250, twice a month for those between 250–500, and at least once a week for areas with more than 500 residents. When available, Ministry-owned health facilities in these regions can also be used to support service delivery.

Regarding educational infrastructure, 75% of villages and neighborhoods were found to have a primary school, while 47% had a middle school, and only 7% had a high school (Figures 5 and 6). Nevertheless, due to factors such as low or dispersed populations, seasonal migration, and a limited number of students, many primary schools under the Ministry of National Education are closed, despite having physical structures in place. In these cases, students are transported daily to central schools in nearby districts. According to national guidelines (Official Gazette, 2014), this transport distance must range between a minimum of 2 kilometers and a maximum of 50 kilometers. In terms of transportation infrastructure, 77% of the settlements have access to daily minibus services connecting them to district centers. However, in the Southeastern and Central Eastern regions, about 40% of the surveyed areas lack such services. In contrast, daily transport availability is highest in the Central Northern (93%) and Mediterranean (89%) regions.

Topography and agricultural land structure

The analysis of village topography showed that 60% of the settlements are situated on plains, 25% on slopes, and 15% in mountainous terrain. The average land size per household varied by region and terrain. In the Mediterranean and Black Sea regions, the average holding is approximately 24–30 decares, whereas in the Southeastern and South-Central regions, this figure rises to 115 and 122 decares, respectively. On a national scale, the average landholding is calculated as 72 decares. The proportion of irrigable land also varies across regions. The Mediterranean and South-Central regions have the highest share of irrigated land, at 58%. Across all regions, irrigable land accounts for approximately 47% of total agricultural land. When pasture sufficiency for livestock activities is considered, the Central Eastern region stands out, with 77% of settlements indicating adequate pastureland. However, availability is inconsistent across villages, with some reporting sufficient pastureland while others experience shortages.

Livestock activities in villages/neighborhoods

Based on statements from local headmen or council members, livestock farming including both small and large ruminant husbandry is common across the surveyed regions. Beekeeping activities were also reported. The average number of households engaged in livestock farming, as well as the average number of animals, varies by

regional agricultural patterns. The Northeastern region recorded the highest number of households involved in cattle farming (72 households), followed by the Southeastern (69 households) and South-Central (62 households) regions. The Northeastern region also ranks highest in terms of both the number of animals and beehives. This is largely attributed to the region's extensive grasslands, pastures, and meadows, which provide ample forage and reduce feed-related constraints. In addition, the region's rich floral diversity creates favorable conditions for beekeeping.

Employment opportunities and common problems

The study also assessed the availability of employment opportunities either within the villages or in nearby areas accessible for daily commuting. Results showed that the Aegean and Southeastern regions offer the most opportunities for daily wage employment, particularly in agriculture-based industries and the services sector (Figure 7). When asked about pressing local issues, 60% of village headmen or council members reported no significant challenges affecting daily life. However, 40% indicated the existence of major problems, most commonly related to irrigation, product marketing, and labor shortages (Figure 8). These challenges can directly impact agricultural productivity and the livelihood sustainability of rural households.

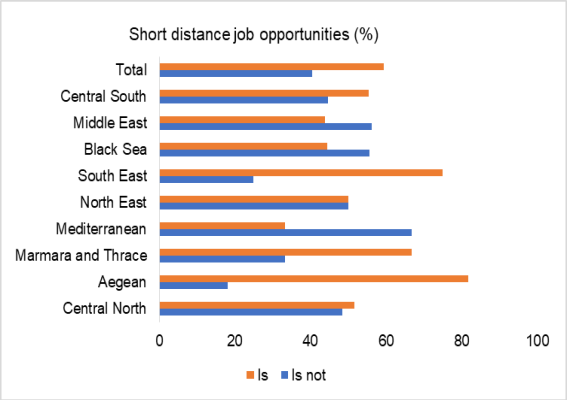

Figure 7. Existence of short-distance job opportunities

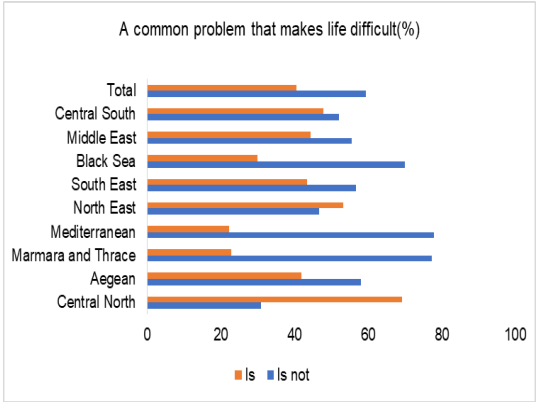

Figure 8. The existence of a general problem

Administrative transformation, demographic structure, and migration dynamics in rural areas

Following the implementation of Law No. 6360, which restructured metropolitan municipalities in Turkey, many villages and towns were reclassified as neighborhoods. Today, provinces with metropolitan status comprise approximately half of Turkey's land area and around 75% of its total population. In recent years, efforts have been made to distinguish between urban and rural neighborhoods within metropolitan municipalities, and in some provinces, the concept of the "rural neighborhood" has begun to take shape. Since this study covers rural areas nationwide, the term "rural settlements" refers not only to traditional villages but also to rural neighborhoods and former towns whose legal status has been dissolved. Among the surveyed settlements, the Mediterranean region stands out with the highest average number of households per village/neighborhood (738), followed by the South-Central (412) and Central Eastern (312) regions.

Regarding year-round residence, 90% of households in the Aegean region occupy their homes permanently. In contrast, only 47% of households in the Black Sea region reside in their homes throughout the year. Across all regions, about 10% of households living in villages or neighborhoods are not engaged in agriculture. Additionally, approximately 6–7% of households are composed of individuals who have migrated elsewhere but either lease or share their land with others or return periodically to engage in agricultural production. The proportion of households that have permanently relocated and sold their land and assets is generally around 6%, but this figure rises to 13% in the South-Central region, 12% in the Northeastern region, and 8% in the Central Eastern region.

Rural development support, cooperatives, and population characteristics

The findings show that, on average, only two households per village receive rural development investment support. In terms of social assistance, about 24 households per settlement benefit from aid programs. The prevalence of agricultural development cooperatives remains low, with over 70% of villages lacking any cooperative organization. However, cooperative activity is relatively higher in the Marmara and Thrace, Mediterranean, and Aegean regions. When examining average village/neighborhood populations, the Mediterranean region again emerges as the most populous, while the lowest average populations are observed in the Marmara and Thrace regions.

Migration trends in villages/neighborhoods

In response to the question directed at village/neighborhood headmen and local leaders about whether their settlement has been primarily receiving or sending migrants over the past 10–15 years, 67% of all responses identified their area as a "migration-sending" settlement. The highest out-migration rates were reported in the Central Eastern (94.4%) and Central Northern (92.3%) regions, while the Mediterranean region (55.6%) recorded the highest in-migration rates (Figure 9). An analysis of migration destinations shows that 53.1% of migrants move to the district or provincial centers to which their village is administratively connected (Table 2). In terms of return migration over the past 10–15 years, the Mediterranean region ranks first with 15 households returning, followed by the Central Eastern region with 10 households (Figure 10). The main reasons cited for returning include emotional attachment to the village and financial difficulties encountered in urban areas.

Table 2. General migration destinations of families

		Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
Provincial-district center	N	2	19	22	22	0	15	1	4	34	119
	%	15.4	61.3	100.0	81.5	0.0	50.0	5.0	22.2	70.8	53.1
Another provincial center	N	6	12	0	5	15	13	16	11	9	87
	%	46.2	38.7	0.0	18.5	100.0	43.3	80.0	61.1	18.8	38.8
Abroad	N	5	0	0	0	0	2	3	3	5	18
	%	38.5	0.0	0.0	0.0	0.0	6.7	15.0	16.7	10.4	8.0
Total	N	13	31	22	27	15	30	20	18	48	224
	%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

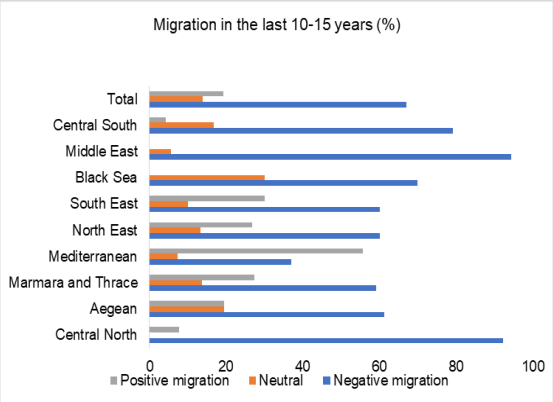

Figure 9. Rural-urban migration status

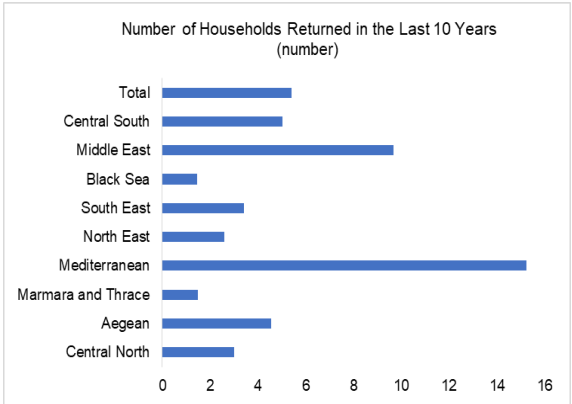

Figure 10. Return to rural areas

Household survey findings – demographic characteristics of respondents

All household-related data collected in the study were analyzed and presented both regionally and in aggregate through structured tables. Table 3 outlines the demographic characteristics of the individual identified as the head of household, who, in most cases, is also the agricultural enterprise owner. However, recognizing that some respondents were not actively engaged in farming, the term "head of household" is used here to represent either the male or female respondent responsible for household decisions. Key demographic indicators such as age, education level, marital status, and social security coverage were examined. The average age of household heads is consistent across regions, with a national mean of 48.4 years. Güreşçi and Yurttaş (2008) found that the number of young heads of households in rural areas was very low due to migration, with households typically consisting of two individuals living together with their spouses. Yakar (2012) reported in their study that the number of heads of households aged 65 and over was four times higher than that of heads of households under the age of 35, noting that the vast majority of adult children had migrated in search of employment opportunities. The gender distribution reveals a significant predominance of male respondents, accounting for 93% of all household heads. In terms of education, 44% of household heads reported having completed primary school, while only 5.3% held a degree from a university or faculty. Marital status data indicate

that 94% of respondents are married. Additionally, 75% of household heads are covered by a form of social security.

Table 3. Demographic information of the household head

		Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
Average Age		47.4	50.4	47.6	49.4	48.0	46.6	51.0	49.3	47.2	48.4
Gender											
Female	N	0	0	12	23	0	69	12	29	17	162
	%	0.0	0.0	5.5	6.1	0.0	12.3	9.3	16	5.5	6.8
Male	N	99	357	208	354	165	493	117	152	291	2229
	%	100.0	100.0	94.5	93.9	100.0	87.7	90.7	84.0	94.5	93.0
Total	N	99	357	220	377	165	562	129	181	308	2398
	%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average number of individuals in the household		4.25	3.84	4.56	3.83	5.68	6.4	4.47	4.63	4.66	4.85
Education status											
No literacy	N	0	0	2	2	1	17	1	0	8	31
	%	0	0	0.9	0.5	0.6	3	0.8	0	2.6	1.3
Primary school	N	14	167	124	135	72	278	59	87	117	1053
	%	14.1	46.8	56.4	35.8	43.6	49.5	45.7	48.1	38	43.9
Middle school	N	24	72	32	89	45	107	16	40	77	502
	%	24.2	20.2	14.5	23.6	27.3	19	12.4	22.1	25	20.9
High school	N	50	96	47	137	47	137	40	48	82	684
	%	50.5	26.9	21.4	36.3	28.5	24.4	31	26.5	26.6	28.5
University	N	11	22	15	14	0	23	13	6	24	128
	%	11.1	6.2	6.8	3.7	0	4.1	10.1	3.3	7.8	5.3
Total	N	99	357	220	377	165	562	129	181	308	2398
	%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Marital status											
Married	N	96	344	210	339	147	543	114	173	279	2245
	%	97.0	96.3	95.5	89.9	89.1	96.6	88.4	95.6	90.6	93.6
Single	N	3	13	10	38	18	19	15	8	29	153
	%	3.0	3.7	4.5	10.1	10.9	3.4	11.7	4.4	9.4	6.4
Total	N	99	354	220	377	165	562	129	181	308	2398
	%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Social security											
None	N	19	39	32	66	52	261	19	65	41	594
	%	19.2	10.9	14.5	17.5	31.5	46.4	14.7	35.9	13.3	24.7
There is	N	80	318	188	311	113	301	110	116	267	1804
	%	80.8	89.1	85.5	82.5	68.5	53.6	85.3	64.1	86.7	74.7
Total	N	99	357	220	377	165	562	129	181	308	2398
	%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Current household assets: past and future outlook

As part of the survey, household heads were asked about their current assets, including land ownership, livestock holdings, residential property, and agricultural structures such as barns. In addition, their current debt status was also explored. The responses varied depending on the type and nature of assets reported (Table 4). The data collected also offer insight into changes in household wealth compared to ten years ago, as well as expectations regarding asset status over the next decade. On the other hand, considering that small family enterprises are predominant in rural areas, it can be observed that land and livestock ownership typically resides with the father as long as he is alive, thereby perpetuating his authority within the household (Ayyıldız et al.).

Table 4. Current assets of the household

	Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
Owned land (da)	340.1	21.2	97.4	23.3	65.4	60.8	29.2	49.4	237.6	84.4
Rent (da)	130.3	6.0	55.8	7.1	8.3	19.8	9.0	12.2	92.1	31.0
Partner (also)	44.9	3.4	23.9	2.4	12.4	5.5	9.9	6.7	29.0	11.9
Cattle (head)	4.9	2.8	18.6	1.3	20.0	1.6	6.3	4.6	9.7	6.2
Ovine (head)	25.3	9.4	14.8	6.1	23.7	13.5	3.8	19.4	39.5	16.3
Stable (head)	10.9	10.0	19.5	3.3	29.2	7.2	12.9	8.8	25.8	12.6
Corral (head)	42.7	16.3	23.7	14.2	38.1	24.3	9.7	27.8	73.7	29.0
Tractor	0.8	0.7	0.8	0.8	0.5	0.6	0.6	0.6	0.8	0.7
Home	2.1	2.1	2.3	2.2	2.0	2.1	2.1	2.0	2.1	2.1
Income	2.1	1.9	2.2	2.1	1.9	1.8	2.1	2.1	2.2	2.0
Debt	2.1	2.1	2.3	2.2	2.2	2.0	2.3	2.2	2.2	2.1

Note: House; if old, 1. if available, 2. if new, 3. Tractor; if no, 0. if available, 1. Income; if bad, 1. if moderate, 2. if good, 3. Debt; if much, 1. if moderate, 2. if little, 3.

Household asset status: retrospective and prospective evaluation

Respondents were asked to provide clear and quantifiable information regarding their asset ownership. For instance, land assets were reported in decares, livestock in headcount, while income levels were assessed on an ordinal scale as “poor,” “moderate,” or “good,” and debt status was categorized as “high,” “moderate,” or “low.” This method enabled households to self-assess their economic situation within a structured and comparable framework. According to the aggregated results across all regions, the average landholding per household was found to be 84 decares. On average, households owned 6.2 head of large livestock and 16.3 head of small livestock. Moreover, barn and shelter capacities were reported to be roughly double the size of the existing animal population. Almost all households owned at least one tractor, and their homes were described as livable and functional. In general, both income and debt levels were evaluated as moderate (Table 4).

Household heads were also asked to compare their current asset status with that of ten years ago, as well as to project potential changes for the next decade. This comparative perspective provides valuable insights into the sustainability of agricultural production at the household level. The retrospective evaluation revealed that, ten years ago, most households possessed greater land and livestock assets, with correspondingly larger barn and shelter capacities. It was also noted that many households, which now own at least one tractor, previously owned multiple tractors. Their homes were relatively newer at the time, and although household income was higher, debt levels were also reported to be more burdensome (Table 5).

Table 5. Comparison of the household's assets 10 years ago with the current situation

	Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
Owned land	2.1	2.1	2.0	1.9	2.0	2.0	2.1	1.9	1.7	1.9
Rent	2.0	2.1	1.8	2.0	2.0	2.0	1.9	1.9	1.8	1.9
Partner	1.7	1.9	1.8	2.0	2.0	2.0	1.9	2.0	1.9	2.0
Bovine	1.8	2.0	1.7	2.0	2.3	2.1	2.3	1.7	1.9	2.1
Small Bovine	2.1	2.1	2.2	2.0	2.0	2.1	2.0	1.3	2.0	2.0
Stable	2.0	2.0	1.9	2.0	2.0	2.0	2.0	1.8	1.9	2.0
Corral	2.0	2.0	1.9	2.0	1.9	2.0	2.0	1.3	1.9	1.9
Home	2.0	2.0	1.9	1.9	2.0	2.0	1.9	2.3	1.9	2.0
Tractor	2.0	2.0	1.9	1.9	2.0	1.9	1.9	2.0	1.9	2.0
Income	1.9	2.1	2.0	2.0	2.2	2.2	2.1	2.1	2.1	2.1
Debt	2.2	2.1	2.2	2.3	2.2	2.4	2.3	2.0	2.2	2.3

Note: 1 if less, 2 if same, 3 if more

Asset expectations of households for the next decade

When comparing current asset levels with projections for the next ten years, most household heads across regions anticipate little to no change in their overall asset holdings. Despite this, there is a prevailing expectation

of increased income in the coming decade. Many respondents believe that, although they do not foresee an expansion in livestock numbers primarily due to rising feed costs and maintenance expenses—their income growth will be driven by the expansion of land ownership. However, the outlook on debt is more pessimistic. A significant proportion of households expect their debt burden to grow over the next ten years (Table 6). These expectations reflect both economic uncertainties and structural challenges in rural agricultural systems, particularly in relation to input costs and financial sustainability.

Table 6. Comparison of potential assets of household in 10 years with the current situation

	Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
Owned land	2.5	2.5	2.2	2.5	2.8	2.6	2.8	2.6	2.5	2.5
Rent	2.6	2.9	2.5	2.8	3.0	2.9	2.8	2.8	2.7	2.8
Partner	2.9	2.8	2.8	3.0	3.0	2.9	2.7	3.0	2.9	2.9
Bovine	2.7	2.7	2.3	2.9	2.5	2.7	2.1	2.2	2.7	2.6
Small Bovine	2.9	2.9	2.6	2.9	2.8	2.8	2.9	1.8	2.8	2.7
Stable	3.0	2.9	2.8	3.0	2.9	2.9	2.9	2.5	2.8	2.9
Corral	3.0	3.0	2.9	3.0	3.0	2.9	3.0	1.8	2.9	2.9
Home	2.9	3.0	2.8	3.0	3.0	2.9	2.9	2.5	2.8	2.9
Tractor	2.9	2.9	2.7	2.9	2.9	2.8	2.9	2.9	2.8	2.9
Income	1.9	2.5	2.7	2.3	2.1	2.4	2.2	2.1	2.5	2.4
Debt	2.1	2.4	2.1	2.1	2.4	2.3	2.0	2.8	2.5	2.2

Minimum agricultural resources required for household livelihood

As part of the survey, household heads were asked to estimate the minimum amount of land and livestock needed for a family to maintain a basic livelihood in their region. The responses to this question are summarized in Table 7. According to the findings, it was determined that, on average, a household requires approximately 81 decares of irrigated land, 90 decares of dry land, 16 head of large livestock, and 70 head of small livestock to sustain a viable living. These estimates vary across regions, reflecting differences in climate conditions, land productivity, and agricultural potential.

Table 7. Average land and livestock assets for a family's minimum standard of living in the region

	Land Asset (da)		**Livestock Asset (head)**	
	Irrigated Land	Dry Land	Cattle-Buffalo	Sheep-Goat
Central North	220.4	239.6	12.8	33.2
Aegean	26.3	39.3	14.8	69.7
Marmara and Thrace	66.2	129.1	23.4	72.9
Mediterranean	25.0	63.5	12.8	73.5
North East	124.2	51.4	34.7	82.1
South East	77.1	100.7	11.0	60.3
Black Sea	47.3	18.0	17.5	58.9
Middle East	84.0	91.3	7.7	64.1
Central South	173.7	138.3	18.8	97.9
General	80.8	90.3	15.8	70.3

Perceptions of agricultural income sufficiency and non-agricultural income sources

While most household heads expressed that their current agricultural income is generally insufficient, some indicated that it fluctuates between being adequate and inadequate depending on the circumstances. Regionally, perceptions of insufficient income were most prevalent among respondents in the Southeastern and Northeastern regions. In contrast, household heads in the Mediterranean and Central Northern regions tended to describe their income as neither sufficient nor insufficient. When non-agricultural income sources were analyzed, it was found that over 50% of households in the Black Sea, Marmara–Thrace, Aegean, and Southeastern regions had access to income outside of agricultural activities. The highest average annual non-agricultural income was observed in the Black Sea region, amounting to 2,381.5 $ while the lowest was recorded in the Central Eastern region at 914.2 $. Across all regions, the average annual non-agricultural income stood at 1,328.3 $.

Regarding their perceived income status compared to other households in the same village, 66% of respondents reported that their income was "neither sufficient nor insufficient." This perception likely stems from the inherent volatility of agricultural production, which is heavily influenced by natural conditions, fluctuating market prices, and rising input costs. Moreover, in rural contexts where livelihood expectations are often shaped by a more fatalistic worldview, income sufficiency is sometimes equated with simply avoiding hunger and homelessness suggesting that "adequacy" is a highly subjective and relative concept. Meanwhile, the share of respondents who considered their income to be sufficient in comparison to other villagers was 25%, and these households were predominantly located in the South-Central, Black Sea, and Marmara–Thrace regions.

Household heads' intentions to migrate

The survey inquired whether household heads had intentions to migrate from their current village or neighborhood. Nationally, 79.7% of respondents reported no desire to leave their rural communities, while 16.7% expressed a willingness to migrate. Regionally, the highest inclination to migrate was observed among respondents in the Southeastern region, where 31.7% indicated an intention to relocate. Conversely, the lowest rate of migration intention was recorded in the Central Northern region, suggesting greater attachment or satisfaction with local living conditions in that area.

Factors influencing migration decisions of household heads

The Central Eastern region had the highest rate of undecided respondents regarding migration intentions, with 8.8% expressing uncertainty. In contrast, the Central Northern region recorded the highest proportion of household heads who firmly stated they did not intend to migrate. Among those considering migration, the majority indicated a preference for relocating to the provincial or district center to which they are administratively connected, and most expressed a desire to move with their entire family. When household heads who were not inclined to migrate were asked about their reasons (Table 8), responses revealed a wide range of economic, social, and emotional factors. Across all regions, the most frequently cited reason (58.5%) was the need to manage agricultural land. Additionally, 33.8% stated they would not be able to sustain themselves financially in urban settings, 30.5% mentioned their responsibility to care for livestock, and 30.4% reported that their current income in the village was sufficient. On the social and emotional side, 49.6% expressed a deep attachment to rural life, while 40.6% noted that their age made relocation impractical. Furthermore, 31.7% indicated that they could not imagine leaving the village where they were born and raised.

Table 8. Reasons for household heads who do not want to migrate (%)

	Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
I have land to take care of	66.7	62.7	79	69.2	58.4	36.9	55.6	40.5	63.4	58.5
I love rural life. I can't give it up	36.7	53.5	69.6	63.8	50.4	38.5	41.9	35.9	43.4	49.6
I can't leave the rural at my age	28.9	38.9	57.5	35.6	53.6	32.8	60.7	31.3	40.8	40.6
I can't make a living in the city	41.1	60.1	18.2	32.6	34.4	37.4	28.2	27.5	27.2	35.7
The city is not attractive. too crowded and complicated	25.6	25.7	56.4	37.7	37.6	28.1	39.3	26.7	32.5	33.8
I can't leave the rural where I was born and raised.	21.1	18.2	58.6	41	38.4	27.9	24.8	16	34	31.7
I have livestock to take care of	22.2	23.8	56.9	24.3	55.2	21	42.7	27.5	28.7	30.5
My income in the rural is sufficient	41.1	48.8	31.5	32.3	20	14.2	33.3	16.8	35.1	30.4
Migrants from rural are not doing well	16.7	25.1	6.6	35.9	32.8	5.2	12	7.6	17	18.4
I've emigrated before. It didn't happen	8.9	9.6	4.4	9.6	21.6	9.3	8.5	8.4	6.4	9.2
Other	14.4	6.9	5	11.4	3.2	6.8	12	1.5	3.8	7.1
I don't know where to go and how to get there	11.1	7.6	5.5	6.3	13.6	2.7	13.7	5.3	4.9	6.6
Health reasons	0	3	6.6	1.5	1.6	2.2	0.9	0.8	0.8	2.1
No reason	10	1	0	0.6	0	1.9	0	3.1	2.3	1.6

Motivations behind the desire to migrate

Among household heads who expressed a desire to leave their village or rural neighborhood, the most commonly cited reason was insufficient income, reported by 72% of respondents. This was followed by the lack of adequate land or livestock to maintain a livelihood in the village (53.3%). Additionally, 47.8% indicated the absence of social life in rural areas as a contributing factor, while 42.8% mentioned the need to migrate for educational purposes either for themselves or their children. Households, particularly prioritizing their subsistence needs, are migrating in order to meet their children's educational requirements and in hopes of a better future. This trend signifies a shift of young individuals away from agriculture. A study has indicated that as the education level of young people living in rural areas increases, the likelihood of remaining in agriculture may decrease by a factor of 0.09 (Ayyıldız et al., 2025). Furthermore, studies conducted in various countries have underscored that the highly educated young population tends to exhibit negative attitudes toward agriculture and views it as a last resort in career planning (Miller et al., 2011; Chinsinga and Chasukwa, 2012; Ojebiyi et al., 2015; Ridha and Wahyu, 2017). A further 40.3% stated that they were discouraged by the physically demanding and labor-intensive nature of farming and therefore preferred not to continue in the agricultural sector (Table 9).

Table 9. Reasons of household heads who want to migrate (%)

	Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
Insufficient income	75.0	86.0	68.0	69.7	82.5	75.3	62.5	58.8	45.7	72.0
I do not have enough land/animals for subsistence	75.0	69.8	64.0	60.6	75.0	50.0	50.0	35.3	25.7	53.3
We have no social life	0.0	46.5	56.0	42.4	52.5	51.7	50.0	38.2	37.1	47.8
For my children's education	50.0	41.9	36.0	51.5	50.0	42.1	62.5	47.1	25.7	42.8
Farming is hard and laborious	50.0	51.2	28.0	33.3	37.5	40.4	62.5	32.4	45.7	40.3
For an insured job	50.0	25.6	48.0	18.2	27.5	45.5	25.0	47.1	31.4	38.0
Spouse/children wanting to go to the city	25.0	51.2	56.0	6.1	55.0	24.7	75.0	20.6	37.1	32.8
Desire to find a job for myself and my children in the city	75.0	41.9	48.0	24.2	22.5	32.6	62.5	26.5	0.0	30.5
Insufficient working capital	0.0	25.6	36.0	33.3	67.5	26.4	37.5	14.7	14.3	29.5
Insufficient family labor force	0.0	41.9	36.0	27.3	40.0	25.3	25.0	26.5	5.7	27.5
Health problems	0.0	4.7	8.0	6.1	72.5	12.4	12.5	8.8	0.0	15.3
Expropriation. landslide. flooding etc. compulsory reasons	0.0	0.0	0.0	0.0	17.5	6.2	0.0	0.0	2.9	4.8
Other	25.0	25.6	0	15.2	7.5	3.9	12.5	23.5	20	10.8

Previous migration from within the household

As part of the survey, respondents were asked whether any member of their household had previously migrated (Table 10). The presence of individuals who have already migrated from a household is considered a significant factor that increases the likelihood of further migration, particularly among younger members. Migration by one family member often serves as a catalyst, facilitating or encouraging others to follow. The results indicate that in 42.8% of households across all regions, at least one person had previously migrated. This

suggests a notable pattern of chain migration within rural families, which can influence future demographic shifts and agricultural labor availability.

Table 10. Previous migration status within the household

		Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
None	N	71	181	155	193	83	332	64	91	202	1372
	%	71.7	50.7	70.5	51.2	50.3	59.1	49.6	50.3	65.6	57.2
There is	N	28	176	65	184	82	230	65	90	106	1026
	%	28.3	49.3	29.5	48.8	49.7	40.9	50.4	49.7	34.4	42.8
Total	N	99	357	220	377	165	562	129	181	308	2398
	%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

It can be asserted that with the increase in the number of migrants within households, the likelihood of young individuals considering migration has also risen. This situation is summarized in Table 11 across all regions. There are supporting studies for this finding. One such study indicates that as the number of migrants within a household increases, the probability of young individuals remaining in agriculture decreases by a factor of 0.052 (Ayyıldız et al., 2025). Additionally, another study conducted in Erzurum, Turkey, found a linear relationship between the increase in the number of relatives of migrating farmers and their own desire to migrate (Tasgin et al., 2016).

Table 11. Information on migrants from the household

		Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
N		30	254	194	312	225	374	97	144	190	1820
Ave. age		27	26	28	28	29	30	31	30	32	28
Gender %	M	63.3	59.1	50.5	49.4	68.9	57.5	48.5	49.3	52.1	55.4
	F	36.7	40.9	49.5	50.6	31.1	42.5	51.5	50.7	47.9	44.6
Ave. Migration (person)		0.30	0.71	0.88	0.83	1.36	0.67	0.75	0.80	0.62	0.76
Place of Migration		Ankara Kayseri İstanbul	Manisa İzmir İstanbul	Manisa İstanbul Tekirdağ	Antalya Mersin İstanbul	Bursa İstanbul Kocaeli	İstanbul Batman Ş.urfa	Zonguldak Germany İstanbul	İstanbul Ankara Adıyaman	Konya Kayseri İstanbul	Antalya İstanbul Konya
Reasons for Migration		Job, Mar, Edu	Job, Edu, Mar	Mar, Job, Edu	Mar, Edu, Job	Job, Mar	Job, Mar, Edu	Jop, Mar	Mar, Job, Edu	Job, Mar, Edu	Job, Edu, Mar

Demographic profile of migrants and returnees

Data on individuals who had migrated from the surveyed households reveal that the average age at the time of migration was 28 years, and 55.4% of those individuals were male. In a study conducted by Ayyıldız et al. (2025), a statistically significant relationship was found between the willingness of rural youth to remain in agriculture and their age. Specifically, when considering young individuals aged 15-29, it was estimated that with each one-year (unit) increase in age, the likelihood of rural youth remaining in agriculture could increase by a factor of 0.006. Although migration destinations varied across regions, Istanbul consistently appeared as a common destination. The primary motivation for migration was employment either to find a job or to pursue better work opportunities (Table 11). The proportion of individuals who migrated and later returned to their home villages was found to be 14% at the national level. Return rates were above average in the Central Eastern (20%), Mediterranean (19%), Central Northern (17%), and Aegean (17%) regions. Reasons for return included completing education, retirement, economic difficulties in urban areas, longing for rural life, and health-related concerns.

Continuity of agricultural enterprise

Household heads were also asked whether someone in their family would continue the agricultural activities after them. The responses show that in 72.5% of cases, household heads trust their children to take over and maintain the agricultural enterprises. However, 19.3% of respondents stated that no one would continue their agricultural work, either due to a lack of interest among children or the absence of a potential successor (Table 12). In rural areas, the head of the household (typically the father) holds the ownership of land and livestock as long as they are alive, thereby maintaining their power. On the other hand, the young individuals expected to sustain the business are often reluctant to take on responsibilities for an extended period due to a lack of their own assets or income, leading them to seek other employment or lifestyles (Ayyıldız et al., 2025). Surinam (2009) noted that young people are particularly unwilling to engage in agriculture due to a lack of access to productive assets, such as land, or a lack of control over those assets.

Table 12. The person who will continue the agricultural enterprises after the head of household

		Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
Children	N	67	278	168	316	74	427	68	127	213	1738
	%	67.7	77.9	76.4	83.8	44.8	76	52.7	70.2	69.2	72.5
Relative	N	3	4	0	23	22	18	1	2	23	96
	%	3	1.1	0	6.1	13.3	3.2	0.8	1.1	7.5	4
No one	N	29	68	43	38	54	63	56	49	64	464
	%	29.3	19	19.5	10.1	32.7	11.2	43.4	27.1	20.8	19.3
I have no farm	N	0	7	9	0	15	54	4	3	8	100
	%	0	2	4.1	0	9.1	9.6	3.1	1.7	2.6	4.2

Goran and Jelisavka (2017) emphasized that youth participation in the agricultural sector varies depending on their place of residence. Particularly among students in rural areas, agriculture is often perceived as a less valuable subject or a last resort. Conversely, urban youth generally view agriculture as a "difficult job" that they are unwilling to undertake (Chinsinga and Chasukwa, 2012). Arli et al. (2014) examined individuals aged 18-25 to understand their attitudes toward the agricultural sector and the factors influencing their willingness or unwillingness to engage in farming. Their study linked low agricultural income levels to the reluctance of youth to pursue farming, highlighting that education is a significant factor in enhancing respect for farmers within society and improving the quality of life for farmers. Furthermore, they emphasized the necessity of creating non-agricultural employment opportunities in rural areas.

Projected fate of agricultural enterprises in the absence of a successor

Household heads were asked what would happen to their agricultural enterprise if no one from the family continued farming after them. The most frequent response, given by 55.4% of respondents, was that the enterprise would be leased or entrusted to a sharecropper. In the Northeastern region, the highest proportion of household heads (40%) stated that the enterprise would be sold entirely. Meanwhile, the Southeastern region recorded the highest rate (40.9%) of responses indicating that the enterprise would simply be abandoned without any further use (Table 13).

Table 13. In case of no one continuing the agricultural enterprise in the coming years

		Central North	Aegean	Marmara and Thrace	Mediterranean	North East	South East	Black Sea	Middle East	Central South	General
Completely sold out	N	8	45	45	79	66	80	9	26	62	420
	%	8.1	12.6	20.5	21.0	40.0	14.2	7.0	14.4	20.1	17.5
Shared/ rented out	N	73	224	146	226	48	252	75	113	171	1328
	%	73.7	62.7	66.4	59.9	29.1	44.8	58.1	62.4	55.5	55.4
It just stays like that	N	18	88	29	72	51	230	45	42	75	650
	%	18.2	24.6	13.2	19.1	30.9	40.9	34.9	23.2	24.4	27.1

CONCLUSION

This study involved face-to-face surveys with 224 village/neighborhood headmen and 2398 household heads across 224 rural settlements located in 27 provinces of Türkiye. The findings offer significant insights into rural migration dynamics and the future of agricultural production in the country. Results indicate that approximately 67% of the surveyed villages and neighborhoods are characterized as out-migration areas. This trend is particularly prominent in the Central Eastern (94.4%) and Central Northern (92.3%) regions, whereas the Mediterranean region (55.6%) has emerged as a net in-migration area. Most migrants are in their twenties, and 53.1% relocate to district or provincial centers. The highest return migration rates were observed in the Mediterranean region, largely driven by emotional ties and financial difficulties encountered in urban areas.

Despite widespread rural out-migration, 79.7% of household heads reported no intention to leave their current settlements. Among those who do wish to migrate, economic challenges particularly insufficient income (72%) and lack of sufficient land or livestock (53.3%) are the primary motivating factors. Social isolation, educational needs, and the physical demands of agriculture are also significant contributors.

Approximately 42.8% of households have experienced at least one prior migration, with an average migrant age of 28 and 55.4% being male. Regardless of regional variation, Istanbul consistently appeared as a migration destination, with employment being the predominant reason. Return migration was recorded at 14% nationwide, with the highest rates in the Central Eastern, Mediterranean, Central Northern, and Aegean regions. Common reasons for returning included the completion of education, retirement, economic hardship, longing for rural life, and health concerns.

In terms of agricultural continuity, 72.5% of household heads expressed confidence that their children would continue farming activities. However, 19.3% indicated that no one would take over the enterprise. If agricultural production were to cease, 55.4% of respondents stated the enterprise would be leased or shared, 40% in the Northeastern region would opt to sell, and 40.9% in the Southeastern region would leave the land idle. These findings underscore critical challenges and transformations within rural Türkiye. While a significant proportion of middle-aged rural residents express a desire to remain, the out-migration of youth signals a generational shift that may threaten the future sustainability of agriculture. Although many parents believe their children will continue farming, the broader trends suggest otherwise.

Historical issues such as fragmented land ownership due to inheritance laws and high rural population growthhave resulted in scattered and inefficient land distribution. Many rural migrants retain ownership of their land, leading to excessive parcelization and reduced agricultural productivity. As a result, many agricultural plots are currently fallow, neglected, or abandoned, and related infrastructure has deteriorated. In the long term, the continued out-migration from rural areas poses significant operational and structural challenges for the agricultural sector. The aging farming population and the reluctance of younger generations to engage in agriculture limit the sector's capacity to adopt modern practices. Farmers increasingly avoid making medium- or long-term decisions and, in some cases, abandon agriculture entirely.

To ensure the sustainability of rural life and agricultural production, migration should not be treated solely as a necessity but as a choice. This requires policies that go beyond enhancing household income; they must focus on improving local opportunities and integrating them into regional development strategies. Urban centers attract migrants not only with employment but also with better access to healthcare and education. Therefore, enhancing job opportunities and expanding social security coverage in rural areas while supporting rural employers could contribute to resolving existing issues and reducing migration pressure.

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Conflict of Interest

The authors declare no conflict of interest.

Ethics Statement

The research protocol was approved by the Social and Human Sciences Ethics Committee of Ondokuz Mayıs University under decision no. 310, dated 20.11.2018.

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Original Article

Impact of GA_3 Application at Different Times and Methods on Tomato Growth and Fruit Shelf Life

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ABSTRACT

Gibberellic acids (GAs) are vital plant growth regulators that significantly influence plant growth, development, and responses to stress. This study examined the effects of applying gibberellic acid (GA_3) to tomato plants and their growing medium at various intervals. The focus was on plant growth, fruit development, and postharvest quality. The results indicated that applying GA_3 every two weeks notably enhanced plant height and stem diameter. However, more frequent applications had a negative impact on fruit size, overall yield, and root fresh weight. Regarding postharvest quality, tomatoes treated with GA_3 every four weeks experienced less weight loss and decay, mainly when GA_3 was applied through the growing medium. Furthermore, plant applications helped maintain the brightness of the fruit peel color. These findings underscore the importance of optimizing the timing and method of GA_3 application to balance growth promotion, yield, and postharvest quality effectively. Future research should investigate alternative application strategies to maximize the benefits of GA_3 while minimizing potential drawbacks.

Key words: Gibberellic acid, *Solanum lycopersicum* L., plant development, plant growth regulators, postharvest

GA_3 Uygulamasının Farklı Zaman ve Yöntemlerle Domates Bitkisi Büyümesi ve Meyve Raf Ömrü Üzerindeki Etkisi

ÖZ

Gibberellik asitler, bitki büyümesini, gelişimini ve strese verdiği tepkileri önemli ölçüde etkileyen hayati bitki büyüme düzenleyicileridir. Bu çalışma, çeşitli aralıklarla domates bitkilerine ve yetiştirme ortamlarına gibberellik asit (GA_3) uygulamasının etkilerini incelemiştir. Odak noktası olarak bitki büyümesi, meyve gelişimi ve hasat sonrası kalitedeki etkiler incelendi. Sonuçlar, GA_3'ün iki haftada bir uygulanmasının bitki boyunu ve gövde çapını önemli ölçüde artırdığını göstermiştir. Ancak, daha sık uygulamalar meyve boyutu, genel verim ve kök taze ağırlığı üzerinde olumsuz bir etki göstermiştir. Hasat sonrası kalite açısından, her dört haftada bir GA_3 ile muamele edilen domatesler, özellikle GA_3 yetiştirme ortamı yoluyla uygulandığında daha az ağırlık kaybı ve çürüme göstermiştir. Ayrıca, bitki uygulamaları kabuk renginin parlaklığının korunmasına yardımcı olmuştur. Bu bulgular, büyüme teşviki, verim ve hasat sonrası kaliteyi etkili bir şekilde dengelemek için GA_3 uygulamasının zamanlamasını ve yöntemini optimize etmenin önemini vurgulamaktadır. Gelecekteki araştırmalar, GA_3'ün faydalarını en üst düzeye çıkarırken olası dezavantajlarını en aza indirmek için alternatif uygulama stratejilerini araştırmalıdır.

Anahtar kelimeler: Giberellik asit, *Solanum lycopersicum* L., bitki gelişimi, bitki büyümeyi düzenleyicileri, hasat sonrası

INTRODUCTION

The growing demand for efficient and sustainable agricultural practices has increased interest in plant growth regulation to enhance crop productivity and quality (Pérez-Jiménez et al., 2015). One promising approach involves using plant growth regulators (PGRs), organic compounds that influence various physiological processes even at low concentrations (Pérez-Jiménez et al., 2015; Rostami and Azhdarpoor, 2019). According to the Environmental Protection Agency (EPA), PGRs can modulate plant growth by altering key physiological mechanisms (Fishel, 2006). Their widespread adoption in commercial agriculture is attributed to their cost-effectiveness and environmentally sustainable nature (Cassina et al., 2011). However, the effectiveness of PGRs depends on several factors, including concentration, application method, environmental conditions, and plant-specific physiological responses (Singh et al., 2018; Rostami and Azhdarpoor, 2019).

Among the various classes of PGRs, gibberellins (GAs) are particularly important due to their ability to regulate key developmental processes such as seed germination, stem elongation, flowering, and root formation (Plackett and Wilson, 2016; Rostami and Azhdarpoor, 2019; Alharby et al., 2021). Additionally, GAs influence physiological functions such as stomatal conductance and photosynthesis while mediating plant responses to environmental stressors, including temperature fluctuations, light availability, and water scarcity (Iqbal et al., 2011; Gupta and Chakrabarty, 2013). While over 250 gibberellins have been identified, only a subset exhibit significant biological activity (El Sabagh et al., 2022). Among them, gibberellic acid (GA_3) is the most widely utilized in commercial agriculture, recognized for its role in stimulating cell elongation and division, thereby enhancing fruit growth and yield (Serrani et al., 2007; Li et al., 2011; Ben Rhouma et al., 2020). Furthermore, GA_3 has been reported to improve crop productivity under suboptimal growing conditions (Khalloufia et al., 2017; Rahman et al., 2019).

Tomato (*Solanum lycopersicum*), a globally significant horticultural crop, is cultivated over 4 million hectares worldwide (FAOSTAT, 2022). Given the increasing consumer demand for high-yield, long-lasting produce, optimizing the use of GA_3 in tomato production is of considerable interest. Research indicates that GA_3 application promotes stem elongation (Bukovac and Witter, 1956), increases fresh weight (Bukovac and Witter, 1956; Rappaport, 1956), and enhances flowering and fruit set (Witter and Bukovac, 1957). Additionally, it has been linked to improved photosynthetic capacity, shoot elongation, leaf expansion, and extended postharvest shelf life (Moncada et al., 2020; Vetrano et al., 2020). However, GA_3 effects vary depending on species, cultivar, and environmental factors. For instance, while GA_3 increases fruit weight in pineapples (Li et al., 2011) and facilitates root development in peas through mycorrhizal associations (Yaxley et al., 2001), it promotes vegetative growth in strawberries. However, it may reduce fruit size and yield (Qureshi et al., 2013). These inconsistencies underscore the need for further research to refine GA_3 application strategies tailored to specific crops and growing conditions.

Despite its known benefits, the optimal timing and method of GA_3 application in tomato production remain unclear due to variability in cultivar responses and environmental interactions. This study investigates the effects of different GA_3 application intervals on tomato plant growth, fruit development, and postharvest shelf life. By examining these physiological and postharvest responses, this research seeks to optimize GA_3 application strategies to enhance yield, fruit quality, and storage longevity, thereby contributing to improved tomato production practices.

MATERIALS AND METHODS

Plant Growing Conditions

The experiment was conducted in a gothic-style, climate-controlled, automated hydroponic research greenhouse at the Department of Horticulture, Faculty of Agriculture, Kırşehir Ahi Evran University. The greenhouse maintained a daytime temperature of 24°C and a nighttime temperature of 16°C, with humidity levels ranging from 60% to 65%.

On May 18, 2018, tomato seedlings of the Altess variety (De Ruiter-Bayer, F1 hybrid) were planted in 8-liter pots positioned on 4-meter-long gutters, using cocopeat as the growing medium. The first and last plants in each gutter were excluded from measurements and analyses to minimize edge effects. An automated system was utilized to control the irrigation and fertilization's pH and electrical conductivity (EC) throughout the experiment. The tomato plants were irrigated with a modified Hoagland nutrient solution tailored to their developmental needs.

The application of gibberellic acid (GA_3) at a concentration of 100 mg L^{-1} began on May 30, 2018. Two application methods were used: GA_3 was applied directly to the plants (P) and the growing medium (M). Both treatment groups received GA_3 at five different intervals, while a control group consisted of plants that did not receive any treatment. Table 1 provides a detailed overview of the treatments.

Table 1. GA_3 treatments

Treatment Method (TM)	Treatment Period (TP)
Control (C)	Control (0)
Plant (P)	Once at the beginning (1)
Medium (M)	Once in every week (2)
	Once in every 2 weeks (3)
	Once in every 3 weeks (4)
	Once in every 4 weeks (5)

Plant Height and Stem Diameter

The plants' heights were measured on three different dates: July 6, July 25, and August 31, 2018. The measurements were taken from the pot level to the tip of the top shoot. The stem diameter was also recorded as 5 cm above the pot level.

Leaf Pigment Content

Leaf tissue pigment levels, including chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids, were measured following the method described by Arnon (1949). Leaf samples weighing 0.2 grams were homogenized in 8 milliliters of 80% acetone and then centrifuged at 10,000 rpm at 4 °C. The supernatants were analyzed using a spectrophotometer at 470 nm, 645 nm, 652 nm, and 663 nm. The amounts of pigments were calculated using the formulas provided by Lichtenthaler (1983).

$$\text{Total chlorophyll} = \frac{\text{A652} \times 27.8 \times 20}{\text{Sample weight}}$$

$$\text{Chlorophyll a} = \frac{(11.75 \times \text{A663} - 2.35 \times \text{A645}) \times 20}{\text{Sample weight}}$$

$$\text{Chlorophyll b} = \frac{(18.61 \times \text{A645} - 3.96 \times \text{A663}) \times 20}{\text{Sample weight}}$$

$$\text{Carotenoid} = \frac{((1000 \times \text{A470}) - (2.27 \times \text{Klo. a}) - (81.4 \times \text{Klo. b}) / 227) \times 20}{\text{Sample weight}}$$

Fruit Dimensions and Yield

During the research period, tomatoes were harvested on seven different dates. The fruits from each plant were weighed and recorded to determine the yield per plant. In addition, the dimensions (width and length in millimeters) and weight of the fruits for each treatment were measured.

Stem and Rroot Fresh Weight

To determine the weight of the stems and roots, the plants' stems were cut at the same level as the root collar. Their fresh weight was then measured by weighing them. Next, the roots were cleaned of cocopeat, washed, and dried before measuring their fresh weight.

Shelf-Life Parameters

Measurements taken included weight loss, color (L*, a*, b*), titratable acidity (expressed as a percentage of citric acid), soluble solid content (SSC), and the percentage of rotten fruit. Peel color measurements of the tomato fruits were obtained using a CR-200 Minolta colorimeter in the CIE L*, a*, and b* color space. SSC was measured as a percentage using a Leica refractometer. To determine titratable acidity, 5 mL of fruit juice was extracted and diluted with 50 mL of pure water, which was then titrated with a 0.1 N NaOH solution using an automatic titrator (Mettler Toledo DL 50 Graphix). The results were reported as a percentage of citric acid. Additionally, the weight of the tomatoes was recorded on days 0 and 7 to assess weight loss.

Statistical Analyses

The study was conducted with three replicates, each consisting of 14 plants, following a randomized complete block experimental design. Additionally, each replicate included shelf-life studies using 10 tomato

fruits. The collected data were analyzed using ANOVA with the MINITAB software package at a significance level of $P \leq 0.05$. After conducting the ANOVA, the Duncan Multiple Range Test was applied using the MSTAT-C software package to identify significant differences from the variance analysis.

RESULTS AND DISCUSSION

Plant Height and Stem Diameter

No significant interactions were observed between the treatment methods and treatment intervals for plant height and stem diameter, suggesting that each variable acted independently (Table 2). However, GA_3 application consistently resulted in taller plants compared to the control group, with the most pronounced effect observed when applied every two weeks. Similarly, stem diameter measurements were significantly greater in both plant and medium treatments compared to the control, which exhibited consistently lower stem diameters throughout the study.

The observed increases in plant height and stem diameter following GA_3 application can be attributed to its role in stimulating cell division and elongation, fundamental processes in plant growth (Pérez-Jiménez et al., 2015; Chen et al., 2020; Rana et al., 2020). Similar growth-promoting effects of GA_3 have been documented in various crops, including tomatoes (Mukati et al., 2019), peppers (Singh and Singh, 2019), chickpeas (Iqbal et al., 2001), cowpeas (Emongor, 2007), and peas (Singh et al., 2015). Furthermore, findings by Islam et al. (2023) corroborate these results, demonstrating that multiple GA_3 applications effectively enhance plant height in mung beans.

Overall, these results highlight the effectiveness of GA_3 in promoting vegetative growth, particularly when applied biweekly. Further research is warranted to explore the long-term effects of different application frequencies on overall yield and physiological development.

Table 2. The impact of GA_3 on the height of plants and the diameter of stems.

Factors	Plant Height (cm)	Stem Diameter (mm)
Treatment Method (TM)		
Control	290.07±2.64 c[1]	12.74±0.12 b[1]
Plant	311.19±4.83 a	14.26±0.23 a
Medium	300.42±4.87 b	13.81±0.24 a
Treatment Period (TP)		
0*	290.07±3.85 b[2]	12.74±0.18 b[2]
1	298.59±5.46 b	13.59±0.28 a
2	303.31±6.74 b	13.84±0.37 a
3	317.93±8.31 a	13.96±0.44 a
4	304.24±5.01 ab	13.55±0.33 a
5	289.21±5.52 b	13.93±0.39 a
Significant effects		
TM	0.000	0.000
TP	0.002	0.012
TM × TP	0.087	0.132

[1]Letters indicate differences between treatment methods. [2]Letters indicate differences between treatment periods. *Once at the beginning (1), once in every week (2), once in every 2 weeks (3), once in every 3 weeks (4), once in every 4 weeks (5)

Leaf Pigment Content

A significant interaction between treatment methods and treatment periods was observed for leaf pigment content ($P = 0.000$). As illustrated in Figure 1, the analysis of chlorophyll a, b, and total chlorophyll values across treatment methods and periods indicated that plants in treatment group 5 exhibited the highest leaf pigment content. Additionally, when comparing application methods within each treatment period, the control group generally showed elevated chlorophyll values; however, during treatment period 5, no significant differences were observed among treatments. This suggests that GA_3 application had a limited effect on enhancing chlorophyll content in this study, a trend also reflected in carotenoid values.

These findings contrast with previous studies reporting increased chlorophyll content following GA application. Datta (2009) observed higher chlorophyll levels and enhanced photosynthesis rates in soybeans, while Chauhan et al. (2018) reported a similar effect in oats. Furthermore, Matos et al. (2020) found that carotenoid content increased with higher GA concentrations. Although GA_3 is known to promote plant

elongation, it can also lead to tissue lightening, potentially due to dilution effects from increased water uptake (Kacar et al., 2006; Shah, 2007). In the present study, the observed decline in chlorophyll content with more frequent GA_3 applications may be attributed to accelerated growth, supporting the hypothesis that rapid elongation can result in pigment dilution.

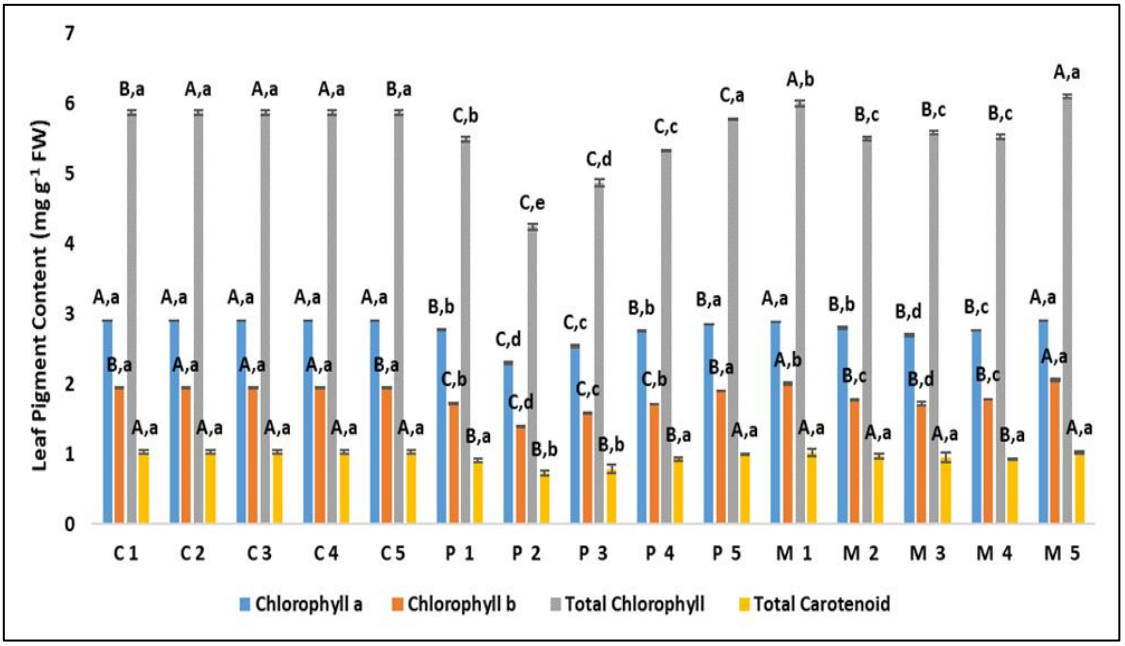

Figure 1. Effect of GA_3 on chlorophyll a, chlorophyll b, total chlorophyll and total carotenoid content. Capital letters represent the differences between treatment methods for each treatment period and the lower letters represent the differences between treatment periods for each treatment method. C: Control, P: Plant, M: Medium. Once at the beginning (1), once in every week (2), once in every 2 weeks (3), once in every 3 weeks (4), once in every 4 weeks (5).

Fruit Dimensions and Yield

The interaction between treatment methods and treatment periods significantly influenced yield, fruit weight, width, and length ($P < 0.05$) (Table 3). Among all treatment periods, period 1 was the most effective in enhancing yield. The control group consistently produced the highest values for all measured parameters when analyzed separately. Notably, only the medium application proved effective in treatment period 1. A similar trend was observed for fruit weight, width, and length, with the control group displaying superior results across all treatments.

Furthermore, increasing the frequency of GA_3 applications was associated with reduced fruit weight, width, and length. While GA_3 enhances fruit set and promotes parthenocarpic fruit production, the resulting fruits are often smaller (Serrani et al., 2007; Mariotti et al., 2011). These findings align with previous studies, which reported that gibberellin-treated fruits tend to be smaller (Jong et al., 2009; Kim et al., 2020). Additionally, yield decreased as GA_3 application frequency increased, supporting observations by Abdel et al. (2011), who found that although GA_3 application in mung beans promoted plant height, it concurrently reduced yield.

These results suggest that while GA_3 may enhance certain aspects of fruit development, its excessive application can negatively impact overall fruit size and yield. Future studies should explore optimal application frequencies to balance growth promotion and fruit quality.

Stem and Root Fresh Weight

A significant interaction was observed between treatment methods and treatment periods regarding the fresh weight of stems and roots (Table 3). While no significant differences in plant fresh weight were noted between the various treatments and the control group, the control group exhibited the highest root fresh weight. Root development is essential for nutrient absorption and plant growth (Araya et al., 2016). A well-coordinated relationship between the shoot and root systems is crucial for maintaining healthy plant growth (Yang et al., 2004; Chu et al., 2014). Both root size and activity influence the efficiency of the photosynthetic process, while the growth and development of the root system depend on photoassimilates produced by the shoots (Zhang et al., 2009; Araya et al., 2016).

Table 3. Impact of GA_3 on yield, fruit weight, fruit width, fruit length, plant fresh weight, and root fresh weight.

Factors	Yield (g)	Fruit Weight (g)	Fruit Width (mm)	Fruit Length (mm)	Plant Fresh Weight (g)	Root Fresh Weight (g)
C × 1	3640±89.7 B,a*	142.02±0.63 A,a	65.77±0.16 A,a	54.86±0.37 A,a	1389±28.7 A,a	348.74±0.35 A,a
C × 2	3640±89.7 A,a	142.02±0.63 A,a	65.77±0.16 A,a	54.86±0.37 A,a	1389±28.7 A,a	348.74±0.35 A,a
C × 3	3640±89.7 A,a	142.02±0.63 A,a	65.77±0.16 A,a	54.86±0.37 A,a	1389±28.7 A,a	348.74±0.35 A,a
C × 4	3640±89.7 A,a	142.02±0.63 A,a	65.77±0.16 A,a	54.86±0.37 A,a	1389±28.7 A,a	348.74±0.35 A,a
C × 5	3640±89.7 A,a	142.02±0.63 A,a	65.77±0.16 A,a	54.86±0.37 A,a	1389±28.7 A,a	348.74±0.35 A,a
P × 1	3661±26.4 B,a	137.69±6.57 A,a	66.45±0.92 A,a	51.83±0.62 B,a	1422±48.2 A,a	318.88±0.35 B,a
P × 2	2166±56.8 B,d	65.31±7.42 C,d	51.64±2.23 C,d	39.77±1.91 C,c	1021±42.6 B,b	242.77±0.35 C,c
P × 3	2716±44.0 C,c	94.10±6.01 C,c	58.78±1.30 B,c	44.93±1.18 B,b	1285±6.43 A,a	195.17±0.35 C,e
P × 4	3431±76.8 AB,b	94.10±6.01 B,c	58.78±1.30 B,c	44.93±1.18 B,b	1369±45.0 A,a	231.74±0.35 C,d
P × 5	3316±112.0 B,b	116.57±9.08 B,b	62.57±1.71 B,b	49.38±1.15 B,a	1063±28.5 B,b	249.56±0.35 B,b
M × 1	4156±133.0 A,a	135.49±6.18 A,a	65.50±1.09 A,a	50.15±0.59 B,a	1386±102.0 A,a	228.04±0.35 C,d
M × 2	3652±20.3 A,b	116.75±7.40 B,b	62.95±1.42 B,ab	48.35±1.37 B,ab	1386±119 A,a	336.38±0.35 B,a
M × 3	3411±66.0 B,c	108.34±4.62 B,bc	60.72±0.89 B,bc	46.99±1.21 B,b	1340±36.0 A,a	269.46±0.35 B,b
M × 4	3297±8.59 B,c	106.12±2.73 B,bc	59.92±0.14 B,c	46.75±0.51 B,b	1361±47.1 A,a	254.63±0.35 B,c
M × 5	3363±36.1 B,c	95.30±4.38 C,c	57.93±0.86 C,c	47.09±1.08 B,b	1270±84.3 A,a	219.44±0.35 C,e
Significant effects						
TM	0.000	0.000	0.000	0.000	0.000	0.000
TP	0.000	0.000	0.000	0.000	0.002	0.000
TM × TP	0.000	0.000	0.000	0.000	0.003	0.000

*Capital letters represent the differences between treatment methods for each treatment period and the lower letters represent the differences between treatment periods for each treatment method. C: Control, P: Plant, M: Medium. Once at the beginning (1), once in every week (2), once in every 2 weeks (3), once in every 3 weeks (4), once in every 4 weeks (5)

The root system's structure is vital not only for its functional capabilities but also for supporting proper shoot function (Wang et al., 2009). Bidadi et al. (2010) found that increased gibberellic acid (GA) application resulted in greater shoot biomass but inhibited root growth. This effect may be attributed to the heightened sensitivity of roots to GA concentrations (Barboza-Barquero et al., 2015). While gibberellins are critical for promoting root elongation, high concentrations can have inhibitory effects (Tanimoto, 2012; Hedden and Sponsel, 2015).

These findings highlight the complex relationship between GA application, root development, and shoot growth, suggesting that optimal GA concentrations are necessary to promote balanced plant development. Future research should further investigate the effects of GA concentrations on root and shoot dynamics to enhance our understanding of plant growth regulation.

Shelf-Life Parameters

Tomato fruit is highly susceptible to water loss during storage, leading to increased weight loss and negatively impacting fruit quality. Our study revealed significant interactions between treatment type, treatment period, and shelf life regarding weight loss in tomatoes (P = 0.000) (Figure 2). As shelf life progressed, weight loss increased.

When analyzing plant and medium treatments separately, the lowest weight loss values were observed in tomatoes treated with GA_3 once every four weeks. For treatment methods, both plant and medium treatments exhibited weight loss values comparable to those of the control group. However, tomatoes treated with GA_3 every four weeks showed lower weight loss during the 7-day shelf life compared to the control group for both application methods. These findings align with research by Bagnazari et al. (2018), which indicated that pre-harvest GA_3 application reduced weight loss during the storage of bell peppers. The application of GA_3 influences the size of epidermal cells and reduces the activity of enzymes that hydrolyze cell walls, thereby affecting tissue water permeability (Gang et al., 2015). Consequently, the reduced weight loss observed in GA_3-treated tomatoes may be linked to decreased enzyme activity and alterations in water permeability.

Furthermore, the effects of treatment method, treatment period, and shelf life duration on the rate of fruit rot were statistically significant (P = 0.000) (Figure 3). The treatment method significantly influenced the rate of fruit spoilage over the 7-day shelf life, with GA_3 applied to the medium proving to be the most effective. Analysis of treatment periods for each application type revealed that applying GA_3 once every four weeks resulted in the lowest rate of fruit spoilage.

These results suggest that optimizing GA_3 application frequency and method can effectively reduce water loss and decay in tomatoes during storage, thereby enhancing postharvest quality. Future research should further explore the underlying mechanisms by which GA_3 influences fruit tissue properties to improve storage outcomes.

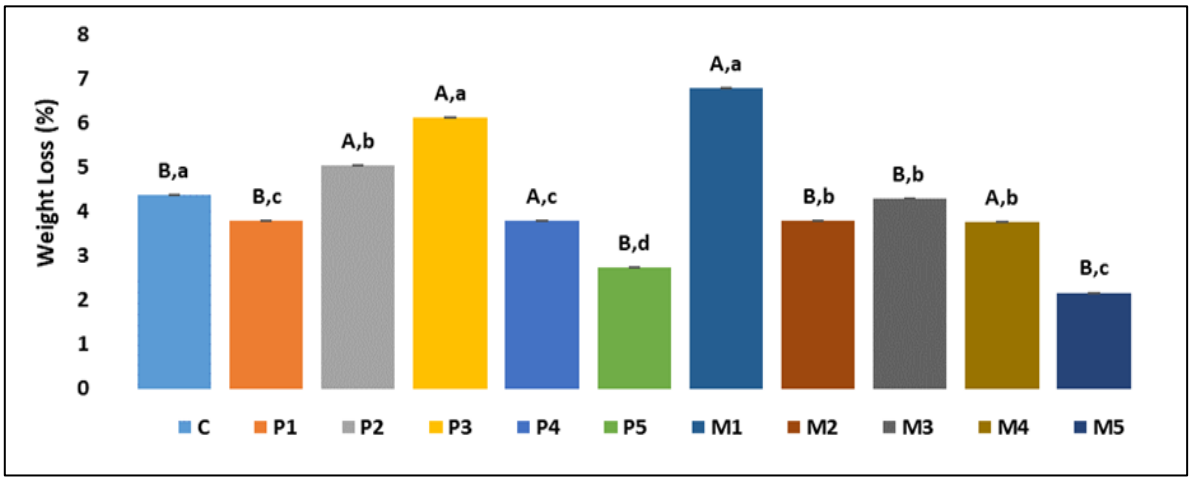

Figure 2. The impact of GA_3 on the weight loss of tomatoes at 7-day shelf life.
Capital letters represent the differences between treatment methods for each treatment period and the lower letters represent the differences between treatment periods for each treatment method. C: Control, P: Plant, M: Medium. Once at the beginning (1), once in every week (2), once in every 2 weeks (3), once in every 3 weeks (4), once in every 4 weeks (5)

In the medium treatment, tomatoes treated with gibberellic acid (GA_3) once every four weeks exhibited the lowest rate of fruit decay. This finding aligns with research by Kirmani et al. (2013), which indicates that pre-harvest GA_3 application can effectively delay fruit decay and extend shelf life. Gibberellins enhance the fruit's resistance to decay by preventing cellular breakdown, contributing to the reduced decay percentage observed with GA3 treatment (Rokaya et al., 2016).

However, the effectiveness of this treatment may vary based on the application method and timing of GA_3, whether applied through foliar spraying or via the growing medium. Understanding these variables is crucial for optimizing GA_3 usage in tomato cultivation to maximize shelf life and minimize decay.

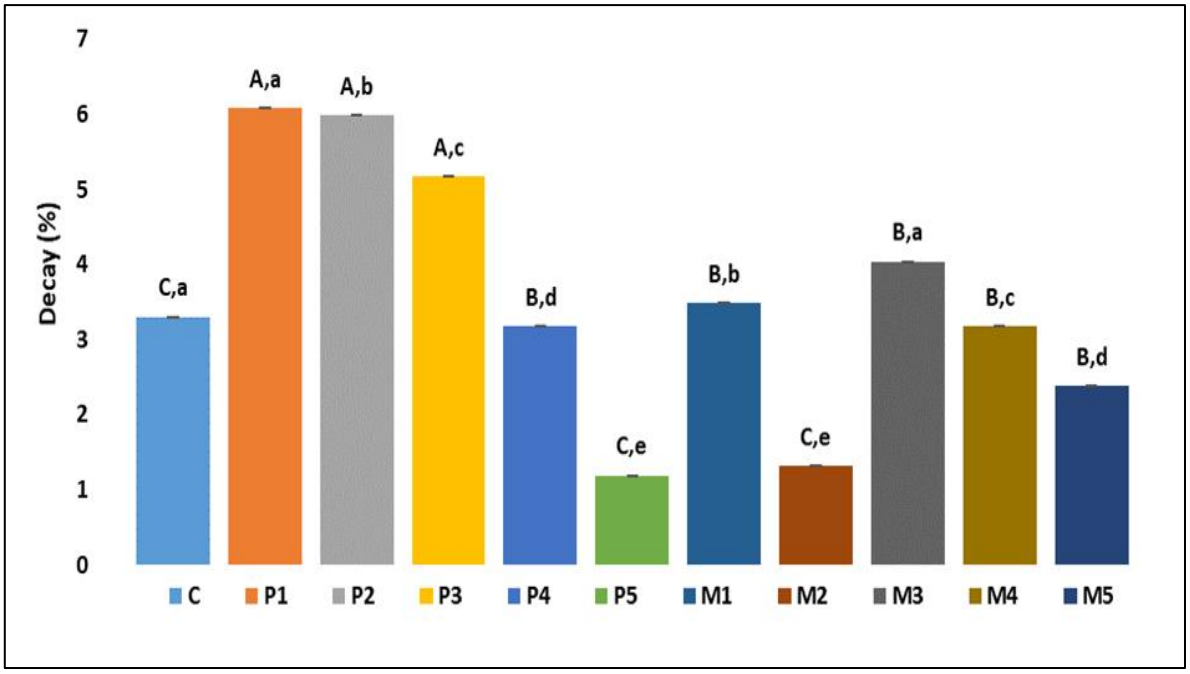

Figure 3. Effect of GA_3 on the percentage of rotten tomatoes at 7-days of shelf life.
Capital letters represent the differences between treatment methods for each treatment period and the lower letters represent the differences between treatment periods for each treatment method. C: Control, P: Plant, M: Medium. Once at the beginning (1), once in every week (2), once in every 2 weeks (3), once in every 3 weeks (4), once in every 4 weeks (5)

After evaluating the color values of tomato fruit peels over 7 days, the interaction between treatment type and shelf-life duration significantly affected the L value, which indicates brightness (see Table 4). Notably, plant treatments were more effective in maintaining peel color brightness throughout the shelf life. In contrast, the L value decreased over time in the control group, while it remained stable in both the medium and plant treatment groups. Previous studies have shown that pre-harvest application of GA_3 can help maintain the L value in kumquats and okra (Cai et al., 2021; Xiao et al., 2022).

The a and b values of tomato peels did not show significant variation, except across different shelf-life periods (see Table 4). As shelf life progressed, the a value increased while the b value decreased. Similar trends in the a and b color values of tomato fruits have been reported by da Costa de Quadros et al. (2020).

Soluble solid content (SSC), which measures the sugars present in fruits and vegetables and is essential for quality assessment (Niu et al., 2019), was significantly influenced by the interaction of treatment methods, durations, and shelf life (see Table 4). SSC levels were higher in plant treatments than in medium treatments, although these levels were statistically like those in the control tomatoes. Additionally, SSC increased with extended shelf life, likely due to increased weight loss over time. This trend aligns with findings from several other studies (Akan et al., 2022; Akan and Horzum, 2023).

Titratable acidity (TA) is a critical quality factor that significantly influences the taste of tomato fruits (Duguma et al., 2022). Treatment methods, durations, and shelf-life periods influenced TA values (see Table 4). Mean value analysis indicated that both the control group and plant treatments exhibited higher TA values than medium treatments. Moreover, significant statistical differences in TA were observed across treatment periods; however, TA levels decreased as shelf life progressed.

Table 4. Impact of GA_3 application on L, a, b values and soluble solid and titratable acidity content.

Factors	L	a	b	SSC	TA
Treatment Method (TM)					
Control (C)	43.80±0.50 ns	27.95±0.64 ns	29.59±0.97 ns	4.60±0.02 A[1]	0.64±0.01 A[1]
Plant (P)	44.35±0.35 ns	28.02±0.37 ns	30.52±0.61 ns	4.48±0.02 B	0.64±0.01 A
Medium (M)	43.36±0.24 ns	27.84±0.35 ns	28.36±0.47 ns	4.09±0.06 C	0.60±0.01 B
Treatment Period (TP)					
0	43.80±0.72 ns	27.95±0.92 ns	29.59±1.40 ns	4.60±0.03 A[2]	0.64±0.01 A[2]
1	43.09±0.48 ns	27.24±0.63 ns	28.30±0.90 ns	4.30±0.09 C	0.59±0.01 B
2	44.99±0.57 ns	28.56±0.60 ns	31.42±1.05 ns	4.46±0.03 B	0.63±0.01 A
3	43.77±0.49 ns	27.73±0.60 ns	29.26±0.94 ns	4.30±0.09 C	0.64±0.02 A
4	43.50±0.46 ns	27.30±0.58 ns	28.75±0.88 ns	4.31±0.11 C	0.63±0.01 A
5	43.87±0.45 ns	28.83±0.59 ns	29.64±0.86 ns	4.36±0.06 BC	0.62±0.01 AB
Shelf Life (SL)					
0. day	44.23±0.40 ns	27.16±0.45 B[3]	30.43±0.77 A[3]	4.31±0.04 B[3]	0.64±0.01 A[3]
7. day	43.44±0.18 ns	28.71±0.27 A	28.56±0.30 B	4.46±0.05 A	0.61±0.01 B
TM × TP					
C × 1	43.80±1.33 ns	27.95±1.70 ns	29.59±2.58 ns	4.60±0.06 A,a[4]	0.64±0.01 ns
C × 2	43.80±1.33 ns	27.95±1.70 ns	29.59±2.58 ns	4.60±0.06 A,a	0.64±0.01 ns
C × 3	43.80±1.33 ns	27.95±1.70 ns	29.59±2.58 ns	4.60±0.06 A,a	0.64±0.01 ns
C × 4	43.80±1.33 ns	27.95±1.70 ns	29.59±2.58 ns	4.60±0.06 A,a	0.64±0.01 ns
C × 5	43.80±1.33 ns	27.95±1.70 ns	29.59±2.58 ns	4.60±0.06 A,a	0.64±0.01 ns
P × 1	41.96±0.31 ns	26.57±0.86 ns	26.85±0.82 ns	4.47±0.02 A,a	0.59±0.04 ns
P × 2	47.14±0.35 ns	29.04±0.74 ns	35.11±0.59 ns	4.43±0.02 AB,a	0.65±0.01 ns
P × 3	44.88±0.31 ns	28.40±0.39 ns	31.24±0.34 ns	4.42±0.07 A,a	0.64±0.06 ns
P × 4	44.00±0.38 ns	27.02±0.31 ns	29.76±0.49 ns	4.55±0.06 A,a	0.65±0.03 ns
P × 5	44.32±0.37 ns	29.12±0.52 ns	30.60±0.69 ns	4.40±0.05 A,a	0.63±0.02 ns
M × 1	43.52±0.32 ns	27.19±0.50 ns	28.45±0.41 ns	3.83±0.13 B,c	0.53±0.02 ns
M × 2	44.04±0.25 ns	28.68±0.38 ns	29.56±0.45 ns	4.33±0.02 B,a	0.59±0.02 ns
M × 3	42.61±0.29 ns	26.83±0.57 ns	26.95±0.63 ns	3.89±0.17 B,bc	0.64±0.03 ns
M × 4	42.71±0.21 ns	26.93±0.58 ns	26.91±0.37 ns	3.79±0.17 B,c	0.60±0.03 ns
M × 5	43.49±0.24 ns	29.43±0.35 ns	28.71±0.36 ns	4.08±0.06 B,b	0.59±0.02 ns
TM × SL					
C × 0. day	44.98±0.93 A,a[5]	26.50±1.11 ns	31.62±1.84 ns	4.47±0.01 ns	0.65±0.01 ns
C × 7. day	42.62±0.09 B,b	29.40±0.47 ns	27.57±0.17 ns	4.73±0.01 ns	0.63±0.00 ns
P × 0. day	44.39±0.59 AB,a	27.75±0.56 ns	31.09±1.02 ns	4.45±0.01 ns	0.65±0.02 ns
P × 7. day	44.31±0.41 A,a	28.29±0.49 ns	29.96±0.68 ns	4.51±0.04 ns	0.62±0.02 ns
M × 0.day	43.32±0.44 B,a	27.23±0.56 ns	28.58±0.87 ns	4.02±0.09 ns	0.61±0.01 ns
M × 7. day	43.40±0.20 AB,a	28.44±0.39 ns	28.15±0.37 ns	4.15±0.09 ns	0.58±0.01 ns
Significant effects					
TM	0.190	0.968	0.132	0.000	0.002
TP	0.240	0.534	0.411	0.000	0.032
SL	0.077	0.010	0.035	0.000	0.007
TM × TP	0.348	0.979	0.650	0.000	0.369
TM × SL	0.046	0.242	0.202	0.061	0.941
TP × SL	0.737	0.918	0.921	0.599	0.125
TM × TP × SL	0.996	0.999	0.999	0.958	0.222

[1]Letters indicate differences between treatment methods. [2]Letters indicate differences between treatment periods. [3]Letters indicate differences between shelf-life periods. [4]First letters represent the differences between treatment methods for each treatment period and the second letters represent the differences between treatment periods for each shelf-life treatment methods. [5]First letters represent the differences between treatment methods for each treatment period and the second letters represent the differences between treatment periods for each shelf life treatment methods. ns: non-significant. C: Control, P: Plant, M: Medium.

CONCLUSION

This study underscores the significant effects of the application method and timing of gibberellic acid (GA_3) on plant growth, yield, and post-harvest quality in tomatoes. Applying GA_3 every two weeks effectively increased plant height and stem diameter; however, more frequent applications adversely impacted fruit size,

overall yield, and root fresh weight. Regarding shelf life, GA_3 treatments applied every four weeks resulted in the least weight loss, with moderate applications being the most effective in reducing fruit rot. Furthermore, applying GA_3 to the plants helped maintain peel color brightness and increased soluble solid content (SSC) and titratable acidity (TA). However, these values remained statistically like those of the control group. These findings highlight the importance of optimizing the frequency and method of GA_3 application to balance growth promotion, yield, and post-harvest quality. Future research should explore application strategies that maximize benefits while minimizing adverse effects.

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Declaration of interests
The authors declare that there are no conflicts of interest related to this article.

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Original Article

Current Status of Flock Management, Care and Feeding Practices in Fattening Sheep Farms in Karacabey District

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ABSTRACT

This study aims to determine some structural features and breeding practices in fattening sheep farms in Karacabey district of Bursa province and to identify the problems encountered in these issues. The material of the study consists of survey data conducted with the owners of 76 fattening sheep farms in Karacabey district in 2025. In the surveyed farms, in addition to the socio-economic characteristics of the farm owners, breeds of sheep raised in the farms, number of mother sheep, care and feeding of mothers and lambs, feeding methods, lamb production, roughage supply, roughage used, silage production, grazing on pasture, fattening period, marketing and frequently encountered diseases were examined. The vast majority of the sheep raised in the farms were Karacabey Merino and the rate in all businesses was calculated as 79.9%. The average ages for disposal of mother rams and sheep in the businesses were found as 4.88 and 6.93 years, respectively. The business owners announced that they obtained an average of 173.75 lambs per year. The mortality rate of lambs from weaning to weaning was determined as 9.11%. The average weaning age of the lambs was 3.78 months and the average fattening period applied was determined as 4.82 months. At the end of fattening, the live weight of the lambs was calculated as 48.33 kg. It was determined that 93.5% of the farm owners took their sheep to pasture and 57.9% kept their animals in pasture all year round. The rate of those receiving feed support in the examined farms was determined to be 15.8%. The farm owners stated that they saw high feed costs, shepherd problem, high medicine-treatment expenses, roughage problem, insufficient support and pasture problem as the most important problems. As a result, it can be said that there are problems in the examined fattening sheep farming farms regarding the care-feeding, benefiting from feed support, silage production and use, lamb deaths and diseases, and that it is important to carry out studies to solve these problems in terms of the profitability of the farms.

Key words: Care-feeding practices, farm owners, grazing on pasture, lamb fattening, marketing, sheep breeding.

Karacabey İlçesindeki Besi Koyunculuğu İşletmelerinde Sürü İdaresi, Bakım Ve Besleme Uygulamalarının Mevcut Durumu

ÖZ

Bu çalışmada, Bursa ilinin Karacabey ilçesinde besi koyunculuğu yapan işletmelerdeki bazı yapısal özelliklerin ve yetiştiricilik konularındaki uygulamaların belirlenmesi ve bu konularla ilgili karşılaşılan sorunların saptanması amaçlanmıştır. Çalışmanın materyalini, 2025 yılında Karacabey ilçesinde yetiştiricilik yapan 76 adet besi koyunculuğu işletmesinin sahipleri ile yapılan anket verileri oluşturmuştur. Anket yapılan işletmelerde, işletme sahiplerinin sosyo-ekonomik özelliklerinin yanı sıra, işletmelerde yetiştirilen koyunların ırkları, anaç koyun sayıları, anaç ve kuzuların bakım ve beslenmesi, yemleme şekilleri, kuzu üretimi, kaba yem temini, kullanılan kaba yemler, silaj üretimi, mera durumu, besi süresi, pazarlama, desteklemeler ve sık karşılaşılan hastalıklar konuları incelenmiştir. İşletmelerde yetiştirilen koyun varlığının çok büyük bir kısmı Karacabey Merinosu olup, tüm

işletmelerdeki oranı %79.9 olarak hesaplanmıştır. İşletmelerde anaç koç ve koyunları elden çıkarma yaşları ortalama olarak sırasıyla; 4.88 ve 6.93 yaş olarak bulunmuştur. İşletme sahipleri yılda ortalama 173.75 adet kuzu elde ettiklerini açıklamışlardır. Kuzuların sütten kesime kadar ölüm oranları %9.11 olarak saptanmıştır. Kuzuların ortalama sütten kesim yaşı 3.78 ay olup, uygulanan besi süresi ortalama 4.82 ay olarak belirlenmiştir. Besi sonunda kuzuların canlı ağırlıklar 48.33 kg olarak hesaplanmıştır. İşletme sahiplerinin %93.5'inin koyunlarını meraya çıkardıkları, %57.9'unun ise hayvanlarını yıl boyu merada tutuğu belirlenmiştir. İncelenen işletmelerde yem desteği alanların oranı %15.8 olarak tespit edilmiştir. İşletme sahipleri, en önemli sorunlar olarak, yüksek yem maliyetleri, çoban sorunu, ilaç-tedavi giderlerinin yüksekliği, kaba yem sorunu, yetersiz destekler ve mera sorununu gördüklerini beyan etmişlerdir. Sonuç olarak, incelenen besi koyunculuğu işletmelerinde, uygulanan bakım-besleme, yem desteğinden yararlanma, silaj üretimi ve kullanımı, kuzu ölümleri ve hastalıklar konusunda sorunlarının olduğu ve işletmelerin karlılığı bakımından söz konusu sorunların çözülmesine yönelik çalışmalar yapılmasının önemli olduğu söylenilebilir.

Anahtar kelimeler: Bakım- yemleme uygulamaları, işletme sahipleri, koyun yetiştiriciliği, kuzu besisi, mera durumu, pazarlama.

INTRODUCTION

Sheep farming is an important component of the livestock sector in Türkiye and around the world, and has great economic value in terms of meat, milk and wool production. Türkiye's geographical and climatic characteristics provide suitable conditions for sheep farming. In addition to contributing to the rural economy, sheep farming also supports economic sustainability in rural areas by reducing migration (Akçapınar, 2000; Arıkan et al. 2013; Karadaş, 2017).

Fattening sheep in Türkiye is a breeding method that aims to produce higher quality and more efficient meat by feeding animals with high nutritional value feeds. Studies show that intensive fattening systems provide higher weight gain and meat quality compared to extensive and semi-intensive systems (Ertuğrul et al., 2009). However, the supply of quality feed and high feed costs are among the biggest challenges for breeders. Breed selection is also of great importance in terms of fattening performance. Breeds such as Akkaraman and Kıvırcık are widely preferred in fattening sheep in Türkiye. The most important reasons for this are that these breeds have advantages in terms of adaptation abilities and feed utilization capacity (Koyuncu et al., 2006). In addition, studies conducted in Elazığ and Erzincan have revealed that planned breeding programs play a critical role in increasing fattening efficiency and carcass quality (Özyürek et al., 2018; Köseman et al., 2022).

Although fattening sheep farming has significant potential in the country's livestock, the sector faces various difficulties and problems. One of the most important problems is that intensive feed costs negatively affect profitability. Producers mostly carry out a farming based on pasture feeding system, but this method cannot provide the high-energy feeds required by fattening lambs (Sezenler et al., 2016; Tüney Bebek and Keskin, 2018). In addition, inadequate shelter conditions and lack of access to veterinary services also negatively affect fattening performance. Marketing and price fluctuations also have a major impact on the profitability of fattening sheep farming. Producers have difficulty reaching larger markets due to instability of meat prices and high transportation costs (Çağlıyan and Durmuş, 2010; Özyürek et al., 2018). In addition, the lack of government incentives designed specifically for fattening sheep farming farms is an important factor hindering the growth of the sector.

Fattening sheep farming is a production activity that is cultivated in all regions of our country. The South Marmara region, where this study was conducted, is in a very good position in this respect. Karacabey district of Bursa province, located in the region, is one of the prominent centers in terms of the density of the number of farms where fattening sheep farming is carried out. The climate and pasture areas of the region provide suitable conditions for fattening sheep farming. However, studies on the structural characteristics, feeding strategies and management practices of these farms are limited. A detailed examination of these factors is of great importance in terms of determining the problems encountered in the sector and developing solution proposals.

This study was planned and conducted to analyze the current status and problems encountered by farms engaged in fattening sheep farming in Karacabey district and its villages. In the study, the socio-economic status, structural features, maintenance-feeding, health-protection and marketing practices in the farms were discussed. By evaluating the obtained data, important problems of fattening sheep farming farms in the region were determined and solution suggestions were made. It can be said that the results of the study can make a significant contribution to the determination of policies aimed at increasing the profitability and ensuring the sustainability of the sheep sector in the region and in Türkiye.

MATERIALS AND METHODS

The material of the study consisted of data obtained from a survey conducted with 76 sheep farming farm owners who are members of the Breeding Sheep and Goat Breeders Association in Karacabey district of Bursa province in 2025. In order to collect the data required for the research, the determined sheep farming farms were visited in January and February of 2025. The prepared survey forms consisting of 35 questions were filled out by face-to-face interviews with the farm owners. The survey forms included questions that would reveal the socio-economic, technical and structural status of the farms. According to the data obtained from the Bursa Breeding Sheep and Goat Breeders Association, the number of registered farms engaged in sheep farming in Karacabey district and villages as of 2024 was determined as 343. When determining the number of samples, first of all, the stratified sample volume formula was intended to be used, but we were informed that no data could be given regarding land information according to Article 3 of the ÇKS Circular No. 23591310-010.06.01 dated 06.06.2017 of the General Directorate of Agricultural Reform (Circular 2014-1) (ÇKS documents of farmers will not be given to any institution or organization except for examinations and investigations to be conducted by judicial and law enforcement forces by provincial and district directorates). Therefore, the proportional sampling method was used, taking into account the number of producers in the provinces and districts in the research area. In this study, probability sampling method was used to ensure the generalizability and reliability of the data. Probability sampling is a method in which the probability of each individual being selected for the sample is known and random selection is based. In this way, the sample can represent the main population and the scientific validity of the study is increased. Sample size was calculated using a standard probability formula. The p and q values in this formula represent the probabilities of the investigated feature being present in the universe (p) and not being present (q = 1 - p). The product of these probabilities is the main factor affecting the variance and therefore the sample size. Especially when there is no prior information, to obtain the highest variance, it is generally taken as; p=0.5 and q=0.5. This approach minimizes the margin of error of the sample and supports the accuracy of the results. The sample volume, i.e. the number of farms to be surveyed, was determined by the Simple Random Sampling Method. The number of farms to be used in the research was calculated as 76 with the help of the formula below, within 95% confidence limits and with a sampling error of 5% (Çiçek and Erkan, 1996; Ceyhan et al., 2015).

$$n=(N * t^2 * p * q)/(d^2 * (N - 1) + t^2 * p * q)$$

n: number of farms to be included in the sample.
N: number of farms in the target population (343 sheep farms).
p: probability of occurrence of the event under investigation (0.50).
q: probability of occurrence of the event under investigation. (0.50).
t: standard normal distribution value (1.96).
d: sampling error (0.05).

The statistical methods used in data evaluation were selected in line with the objectives of the research. In this context, independent descriptive statistics such as frequency, percentage, mean and standard deviation were used. The answers given to the questions asked about the structural and technical problems of the farms through surveys were analyzed through SPSS 22 program and the descriptive statistics and frequency tables obtained were presented (SPSS, 2013).

RESULTS AND DISCUSSION

In the study, the findings regarding the operator profile and demographic characteristics of the farms engaged in fattening sheep farming in Karacabey district and its villages are given in Table 1. The findings in question are largely similar to the results of research conducted in different regions of our country and on this subject. In the study, the average age of the farm owners was calculated as 49 years. This figure was reported as 46.8 years in Sivas (Gezer, 2010), 47.1 years in Elazığ (Yakan et al., 2016) and 49 years in Hakkari (Karadaş, 2018). It was observed that the average age calculated in this study was quite close to the age averages in other provinces. This situation shows that sheep farming is mostly done by middle-aged and older individuals and that the interest of young people in the sector is limited.

Table 1. Average age of business owners, business size, education level, how many years they have been doing sheep farming, why they do this job, and whether they have received training on the subject

Age of Business Owners	
Mean	49.263
Std. Deviation	12.1462
Minimum	24
Maximum	73
Land size of the business	
Mean	169.363
Std. Deviation	316.6368
Minimum	1
Maximum	2000
Educational background	**Ratio (%)**
Primary school	44.7
High school	25
Literate	7.9
Middle school	6.6
University	15.8
Total	**100.0**
Whether the business owners have received training in sheep farming	
No	84.21
Yes	15.79
Total	**100.0**
How many years has he been raising sheep?	
Mean	25.605
Std. Deviation	16.5884
Minimum	2
Maximum	70
Where did he first get the sheep from to start his business?	**Ratio (%)**
Inherited from father	5.3
Inherited from grandfather	28.9
From the state	3.9
Animal market	5.3
From the village	52.6
From the merchant	3.9
Total	**100.0**

In the study, the average land size of the farms was determined as 169.36 da. This value is generally higher than the average land size reported in similar studies conducted in different regions of Türkiye. In the study conducted by Kırmızıbayrak and Akman (2015) in the central districts of Antalya province, the average land size was determined as 85.2 da. Similarly, Çağlıyan and Durmuş (2010) reported an average of 40.6 da in sheep farming farms in the Diyarbakır basin, while Kaymakçı and Sönmez (1996) reported an average farm size of around 60 da throughout Türkiye. In addition, Yakan et al. (2016) reported an average land size of 112.4 da in their study conducted in Elazığ province, and Tüney Bebek and Keskin (2018) reported this value as 95.6 da in Mersin province. These findings show that the farms in Karacabey district are in a more advantageous position compared to many regions in terms of land assets.

In the study, when the education levels of the business owners were examined, it was seen that 44.7% of them were primary school graduates, 25% were high school graduates and 15.8% were college graduates. The high number of business owners who were primary school graduates draws attention to the low level of education. In other studies on the subject, it was reported that low levels of education were also noted in the provinces of Ordu (Alkan and Türkmen, 2021), Niğde (Ceyhan et al., 2015) and Mersin (Tüney Bebek and Keskin, 2018). The low level of education can be seen as a situation that makes it difficult to adopt modern and rational animal husbandry techniques and innovative practices.

It was determined that only 15.8% of the business owners who participated in the survey received training on sheep farming. This situation is important as it shows that a large proportion of 84.21% did not receive any animal husbandry training. In different studies, this rate is much lower, reported as 6% for Karaman province (Şahinli, 2014) and 8.4% for Tokat province (Şahin and Olfaz, 2019), and it was reported that the majority of the producers were engaged in traditional knowledge-based farming. It is noteworthy that the level of education in Karacabey district is 2 times higher than in the mentioned provinces.

Table 2. Values related to the average number of maternal sheep in the farms, breed preference and breeding purpose

Number of breeding rams and ewes in farms	
Mean	141.45
Std. Deviation	151.297
Minimum	16
Maximum	1000
Breed of sheep	**Ratio (%)**
Karacabey Merino	79.9
Merino Crossbreed	5.2
Kıvırcık	3.9
Merino, Ile de France	2.6
Karacabey Merinos, East Friesian	1.4
German Blackhead, Ile de France, Hungarian Merino	1.4
Merino, Ile de France	1.4
Merino, Kıvırcık	2.8
Suffolk	1.4
Total	**100.0**
The purpose of raising this breed	**Ratio (%)**
Breed of the region	34.2
Breed of the region, Meat yield	23.7
Adaptability	18.5
Meat yield	11.8
Personal preference	5.3
Breed of the region, Meat yield	2.4
Breed of the region, Twin rate	1.4
More economical	1.4
For state support	1.3
Total	**100.0**

When the sheep farming experience of the owners of the examined farms is examined, it is seen that this period is quite long and the average period of time they have been involved in sheep farming is 25.6 years. Regarding this period, similar results were reported in the studies conducted in Hakkari (Karadaş, 2018), Niğde (Ceyhan et al., 2015) and Şanlıurfa (Karadaş, 2017) provinces and it was explained that the farm owners have many years of experience. Regarding the places where the farm owners obtain the mother sheep, it was determined that they generally start by obtaining animals from breeding farms and markets. In the studies conducted in Niğde (Ceyhan et al., 2015) and Elazığ (Yakan et al., 2016) provinces, it was stated that breeding unions and local markets are more important as the place of supply of breeding animals. This finding is important in terms of showing that local resources are still at the forefront in animal supply. It is understood that the general trends regarding the farmer profile obtained from the study are similar at the national level, and that the lack of education and young participation continues. The data obtained regarding some characteristics such as the presence of breeding sheep, sheep breed preference and breeding reason of the farms engaged in fattening sheep breeding in Karacabey district are given in Table 2.

Table 3. The average number of lambs obtained by the farms per year, the place where the animals are sold at the end of fattening, the use of concentrated feed, the number of daily feedings and the values related to the determination of the amount of feed to be given

How many lambs do you get in total per year?	
Mean	173.750
Std. Deviation	185.1596
Minimum	15.0
Maximum	1000.0
Where do you sell the lambs at the end of the fattening period?	**Ratio (%)**
Butcher	52.6
Merchant	25.0
Sacrificial	15.8
Butcher, Sacrificial	3.9
Butcher, Sacrificial, Votive	1.3
Butcher, Merchant	1.3
Total	**100.0**
Do you use concentrated feed in lamb fattening?	**Ratio (%)**
Yes	56.6
No	43.4
Total	**100.0**
How many times a day do you feed fattening lambs?	**Ratio (%)**
1 per day	10.93
2 per day	79.44
3 per day	9.63
Total	**100.0**
How do you determine the amount of feed to be given per animal?	**Ratio (%)**
Automatic feeder	57.9
Eye decision	23.7
Experience	18.4
Total	**100.0**

In this study, it was determined that the majority of the farms were small and medium-sized and the average flock size was 141.45 heads. The findings obtained in terms of flock size are similar to the results of the studies conducted in Niğde (Ceyhan et al., 2015) and Sivas (Gezer, 2010) provinces and show that small and medium-sized family farms have an important share in Türkiye's sheep farming. The fact that the most preferred breed (79.9%) in the examined farms was Karacabey Merino indicates that breeds with high adaptation to the region and advantageous breeds in terms of meat yield and quality characteristics are prioritized. Similarly, in a study conducted in Konya province, it was reported that crossbred and high-yielding breeds were preferred for fattening (Özdemir et al., 2017). In general, the structural characteristics of sheep farming farms in Karacabey district are shaped by the selection of breeds compatible with the region and traditional housing practices. However, the need to switch to modern shelters and increase infrastructure investments is clearly evident. The results of the farms' lamb production, marketing location, concentrated feed use and feeding methods are given in Table 3.

The data obtained regarding the annual lamb yield, sales method, feeding habits and feed management methods of the farms engaged in fattening sheep farming in Karacabey district are generally similar to sheep farming in Türkiye. It was determined that the farms examined obtained an average of 173.75 lambs per year. Although this value is similar to the results of the studies conducted in Niğde (Ceyhan et al., 2015) and Elazığ (Yakan et al., 2016) provinces, it is seen that the production potential of the farms in Karacabey region is higher. It was determined that at the end of the fattening period, the lambs were sold to towns (52.6%) and merchants (25%). This situation was also reported in studies in Ordu (Alkan and Türkmen, 2021) and Şanlıurfa (Karadaş, 2017). It is observed that producers prefer to sell to butchers due to direct cash conversion and ease of access to the market.

Table 4. Values regarding the hours at which animals are fed in the farms, how roughage and concentrated feeds are given, silage production, silage use, grazing in pastures and feed support

Which times of day do you feed your sheep outside of the grazing season?	**Ratio (%)**
Morning-evening	81.6
Morning-noon- evening	7.9
Morning	6.6
Evening	3.9
Total	**100.0**
Do you feed roughage and concentrate separately or mixed?	**Ratio (%)**
Separately	75.0
Mixed	25.0
Total	**100.0**
Do you make silage in your farm?	**Ratio (%)**
No	84.2
Yes	15.8
Total	**100.0**
Do you feed silage to mother ewes or fattening lambs?	**Ratio (%)**
No	72.4
Yes	27.6
Total	**100.0**
Do you take your sheep out to pasture?	**Ratio (%)**
Yes	93.5
No	6.5
Total	**100.0**
Do you receive government support for feed?	**Ratio (%)**
No	84.2
Yes	15.8
Total	**100.0**

It was determined that the rate of using concentrated feed in lamb fattening in farms was 56.6% and 43.4% of the farms did not use concentrated feed. The findings obtained are similar to the results of the studies conducted in Burdur (Erdoğan et al., 2018) and Tokat (Şahin and Olfaz, 2019). The low rate of using concentrated feed in farms can be seen as an important problem. Because concentrated feed is of critical importance in terms of fattening performance and carcass quality. It was determined that the lambs fattened in the examined farms were generally fed twice a day (79.4%). This practice is compatible with the feeding frequency recommended in the literature and is important in terms of balanced growth and rational feed consumption (Özdemir et al., 2017). In determining the amount of feed to be given per animal, the use of automatic feeders was prominent (57.9%). 23.7% of the farm owners stated that they determined the amount of feed to be given by eye. This situation was similarly determined in studies conducted in Elazığ (Yakan et al., 2016) and Konya (Özdemir et al., 2017) and reveals that modern systems should be expanded in terms of homogeneous feeding and efficiency. Data on feeding times, feeding method, silage production and use, pasture removal status and whether or not they receive feed support of farms engaged in fattening sheep breeding in Karacabey district are given in Table 4.

Table 5. Values related to the periods of taking sheep out to pasture in the farms

Periods of taking animals out to pasture	**Ratio (%)**
All Year Round (12 months)	57.9
April-August	9.2
April-October	5.3
April-November	3.9
March-December	2.6
April-December	2.6
March-November	2.6
May-October	1.3
May-November	1.3
March-October	1.3
March-November	1.3
January-November	1.3
February-December	1.3
February-November	1.3
No pasture	6.6
Total	**100.0**

When we look at the hours when sheep are fed outside the pasture period, it is seen that 81.6% of the farms feed in the morning and evening. This rate was found to be similar in the study in Tokat (Şahin and Olfaz, 2019) province, and morning and evening feeding is generally a standard practice. In the study, the habit of giving roughage and concentrated feed separately draws attention with a rate of 75%. This approach is important for the animals to better evaluate their rations and for digestive health. In the studies in Mersin (Tüney Bebek and Keskin, 2018) and Elazığ (Yakan et al., 2016), it was reported that separate feeding was common. It was determined that very few of the farms examined (15.8%) produced silage. It was observed that 84.2% of the farms did not produce silage. This rate was similar to the rates in studies conducted in Konya (Özdemir et al., 2017) and Burdur (Erdoğan et al., 2018). However, the low rate of silage making reveals that modern feeding techniques should be adopted more.

The silage feeding rate for mother ewes and fattening lambs was 27.6%, which was found to be similar to the Turkish average. Although silage use is important in maintaining nutritional balance, it was also found to be

at low levels in studies conducted in Elazığ and Ordu provinces (Yakan et al., 2016; Alkan and Türkmen, 2021). In Karacabey district, the rate of sheep being taken to pasture was found to be as high as 93.5%. Similar results were also emphasized in studies conducted in Tokat (Şahin and Olfaz, 2019) and Sivas (Gezer, 2010), indicating that pasture farming is still the basic farming practice. The rate of farms receiving state support for feed was determined to be only 15.8%. This rate can be seen as an important problem since it is insufficient for producers to meet the high feed costs. In similar study conducted in Hakkari province, lack of support was among the main problems of producers (Karadaş, 2018). Data on pasture usage periods and pasture periods of farms engaged in fattening sheep breeding in Karacabey district are given in Table 5.

Table 6. Values related to grain and forage produced in farms

What forages do you grow yourself?	**Ratio (%)**
Dried alfalfa	5.2
Dried alfalfa, Corn, Straw	3.9
Dried alfalfa, Ryegrass, Straw	3.9
Barley, Straw	3.9
Ryegrass, Barley, Straw	3.9
Dried alfalfa, Barley, Wheat	2.6
Hay, Straw	2.6
Dried alfalfa, Straw	2.6
Dried alfalfa, Corn, Straw	2.6
Dried alfalfa, Vetch, Oat, Straw	2.6
Ryegrass	2.6
Barley, Corn, Ryegrass, Straw	1.3
Barley, Dried alfalfa	1.3
Wheat, Barley, Corn	1.3
Wheat, Barley, Corn, Ryegrass	1.3
Hay	1.3
Dried alfalfa, Hay	1.3
Barley	1.3
Corn	1.3
Corn, Vetch, Ryegrass, Straw	1.3
Wheat, Barley	1.3
Corn, Dried alfalfa, Vetch, Straw	1.3
Corn, Dried alfalfa, Ryegrass, Straw	1.3
Corn, Dried alfalfa, Oat, Straw	1.3
Ryegrass, Barley	1.3
Ryegrass, Barley, Oat	1.3
Straw	1.3
Barley, Wheat, Dried alfalfa, Ryegrass, Straw	1.3
Barley, Wheat, Straw	1.3
Barley, Ryegrass, Straw	1.3
Vetch, Oat, Straw	1.3
Barley, Wheat, Oat, Corn	1.3
Dried alfalfa, Hay, Vetch, Straw	1.3
Not grown	34.2
Total	**100.0**

It was determined that 57.9% of the farms examined put their sheep on pasture throughout the year. This rate was found to be similarly high in study conducted in Tokat (Şahin and Olfaz, 2019). This result shows that pasture farming continues to be the basic element in terms of sheep farming. Especially, pasture use throughout the year is an important advantage in terms of reducing feed costs and providing natural nutrition. The rate of

farms where the pasture period changes between April-August, April-October or March-November remained lower. This situation can be interpreted as the width of pasture areas and climatic conditions in Karacabey district allowing grazing throughout the year. However, in Burdur (Erdoğan et al., 2018) and Mersin (Tüney Bebek and Keskin, 2018) provinces, pasture use between certain months is prominent due to seasonal restrictions. It has been determined that the rate of farms that are not put out to pasture is 6.6%, and this rate is at a similar level throughout Türkiye. It is thought that farms that are not put out to pasture have higher costs because they need to implement more intensive feeding and closed fattening practices As a result, the pasture usage habits of sheep farming farms in Karacabey district provide advantages to the region in terms of both economic and production efficiency. However, it is important to spread sustainable pasture management practices against climate change and pasture destruction. The rates of grain and forage produced in the examined farms are given in Table 6.

When the data obtained regarding the feed production status and roughage sources of the farms engaged in fattening sheep farming in Karacabey district are compared with similar studies conducted in different regions of Türkiye, remarkable differences are observed. It was determined that 65.8% of the farms examined produced their own roughage, while 34.2% did not produce any roughage. This rate was observed similarly in the study in Tokat (Şahin and Olfaz, 2019) province, and the inadequacy of forage crop production was emphasized as an important problem. Dry alfalfa, barley straw and ryegrass stand out among the most produced roughage sources. This result was also reported similarly in the studies in Mersin (Tüney Bebek and Keskin, 2018), Konya (Özdemir et al., 2017) and Burdur (Erdoğan et al., 2018). It is understood that breeders do not diversify their forage crops and feed their animals with a limited number of products. The fact that farms that do not produce forage crops feed entirely through purchasing increases costs and negatively affects the profitability of the farm. In addition, it is stated in the literature that even feed production farms mostly focus on single-type feed production and have difficulties in maintaining ration balance (Yılmaz et al., 2019). As a result, it is seen that sheep farming farms in Karacabey district are inadequate in terms of roughage production. It is necessary to inform and support producers about feed crop production and to encourage forage crop diversification as well as efficient use of pasture areas. In the study, the answers given by the business owners when they were asked about the diseases and health problems they encountered most frequently are given in Table 7.

Table 7. Values for the most common diseases in farms

What are the most common diseases you encounter?	**Ratio (%)**
Lameness	15.7
Diarrhea	6.6
Mastitis, Lameness	5.2
Lameness, Brucella	5.2
Mastitis	2.6
Smallpox	2.6
Brucella	2.6
Smallpox, Brucella	3.9
Nail disease	2.6
Lameness, Smallpox	2.6
E. Coli, Diarrhea	1.3
Diarrhea, Smallpox, Brucella	1.3
Parasite, Smallpox	1.3
Brucella, Diarrhea	1.3
Nail disease, Lameness, Brucella	1.3
Nail disease, Scabies, Brucella	1.3
Bloat	1.3
Scabies	1.3
Stillborn	1.3
No disease	31.6
Total	**100.0**

It has been determined that the most common diseases are lameness (15.7%), diarrhea (6.6%), mastitis and infectious diseases such as brucellosis. The findings are similar to the results of other studies conducted in Elazığ (Yakan et al., 2016), Tokat (Şahin and Olfaz, 2019) and Sivas (Gezer, 2010). The results show that foot health problems and infectious diseases are among the most common problems in sheep and animals. Lameness is caused by poor shelter conditions, inadequate hygiene and unsuitable floor structure, and causes serious economic losses for producers. In the studies in Ordu (Alkan and Türkmen, 2021) and Mersin (Tüney Bebek and Keskin, 2018), lameness was also stated as the most common disease encountered by producers. Diarrhea and parasitic infections play an important role, especially in lamb losses. This situation points to the inadequacy of preventive medicine practices and the lack of vaccination programs (Erdoğan et al., 2018). The existence of zoonotic diseases such as brucellosis and smallpox is important for both animal and public health Regular vaccination, herd management and hygiene measures should be increased to prevent the spread of these diseases. As a result, the diseases encountered by sheep farms in Karacabey district largely overlap with those in other regions of Türkiye. It is very important to expand herd health protective measures and education activities and to ensure easy access of producers to veterinary support services.

CONCLUSION

This study was planned to reveal the technical and structural characteristics, maintenance-feeding and herd management practices and the problems encountered by the farms engaged in fattening sheep farming in Karacabey district and villages of Bursa province. For this purpose, the data obtained as a result of the survey studies were evaluated and the current situation of fattening sheep farming in the region was examined. Although the results were generally similar to the problems in Türkiye, some different problems specific to the region were also encountered.

In the study, it was determined that the majority of the farms were small and medium-sized family businesses and the average herd size was around 141 head. It was understood that the farm owners were generally middle-aged and experienced people who had been doing this job for many years, but they used modern breeding practices limitedly due to their low level of education. The widespread preference of the Karacabey Merino breed in farms draws a positive picture in terms of its adaptation to the region and high meat yield. However, the main problems such as difficulty in finding shepherds and workers, high production costs, high feed prices, veterinary, medicine and treatment expenses, pasture problems, excessive medicine, fertilizer and fuel expenses, diseases and lamb deaths, low wool prices, marketing problems, lack of cooperatives and inadequacy of support and incentives come to the fore.

Inadequate silage production and the fact that the need for roughage is largely met through purchasing increases operating costs. Although pasture-based feeding is widespread, seasonal changes and poor pasture quality can negatively affect production efficiency. In addition, producers cannot evaluate the by-products obtained due to low wool prices and experience income loss due to difficulties in marketing channels. Diseases and lamb deaths are among the important problems, and it is clear that preventive health services and vaccination practices need to be increased. The problem of finding shepherds and workers is another important factor that makes the continuity of production difficult.

As a result, it can be said that in order to increase the sustainability and profitability of farms, it is necessary to expand training for producers, strengthen support, encourage local forage production, facilitate access to veterinary services, develop marketing infrastructure, strengthen cooperative activities and increase incentives for shepherd employment.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

***Ömer ŞENGÜL*:** Conceptualization; data curation; formal analysis; investigation; methodology; project administration; writing— original draft; writing—review and editing.

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Original Article

Determination of Factors Affecting Net Profit in Buffalo Milk Production by Different Data Mining Algorithms: A Case Study of Iğdır Province

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ABSTRACT

Buffalo milk is an important animal product because it has more protein and fat content compared to other types of milk. This study aimed to identify the key factors influencing profitability in buffalo milk production using advanced data mining algorithms. Data were collected from 92 buffalo farms in Iğdır Province, Türkiye, in 2016 by using the Simple Random Sampling Method. Among the 4 models developed in the R program, the Multivariate Adaptive Regression Splines (MARS) model demonstrated superior predictive performance based on cross-validation and goodness-of-fit criteria. The results revealed that lactation year (LY) and lactation period (LP) were the most significant variables affecting net profit. Profitability was highest in the seventh lactation year, while extending the lactation period beyond 175 days contributed to linear profit increases. The findings suggest that buffalo producers should adopt management strategies focused on culling buffaloes after the seventh lactation and extending lactation periods to improve economic outcomes. This research highlights the effectiveness of data mining techniques in determining profitability factors and provides recommendations to optimize production efficiency in livestock systems. In future research, more comprehensive models can be developed using larger datasets and additional variables.

Key words: Buffalo milk, Net profit, Data Mining Algorithms, Iğdır province, Türkiye

Farklı Veri Madenciliği Algoritmaları ile Manda Sütü Üretiminde Net Kârı Etkileyen Faktörlerin Belirlenmesi: Iğdır İli Örneği

ÖZ

Manda sütü diğer süt türlerine kıyasla daha fazla protein ve yağ içeriğine sahip olması sebebiyle önemli bir hayvansal üründür. Bu çalışmada, gelişmiş veri madenciliği algoritmaları kullanarak manda sütü üretiminde kârlılığı etkileyen temel faktörlerin belirlenmesi amaçlanmıştır. Veriler, 2016 yılında Basit Tesadüfi Örnekleme Yöntemi kullanılarak Türkiye'nin Iğdır ilinde 92 manda çiftliğinden toplanmıştır. R programında geliştirilen 4 model arasında, Çok Değişkenli Uyarlamalı Regresyon Eğrileri (MARS) modeli, çapraz doğrulama ve uyum iyiliği kriterlerine dayalı olarak üstün tahmin performansı göstermiştir. Laktasyon yılı (LY) ve laktasyon süresinin (LP) net kârı etkileyen en önemli değişkenler olduğunu tespit edilmiştir. Kârlılık yedinci laktasyon yılında en yüksek iken, laktasyon süresinin 175 günden fazla uzatılması doğrusal kâr artışlarına katkıda bulunmuştur. Bulgular, manda üreticilerinin kârlılığını artırması için yedinci laktasyondan sonra mandaları ayıklamaya ve laktasyon dönemlerini uzatmaya odaklanan yönetim stratejileri benimsemeleri gerektiğini göstermektedir. Bu araştırma, kârlılık faktörlerini belirlemede farklı veri madenciliği tekniklerinin etkinliğini ortaya koymakta ve hayvancılık sistemlerinde üretim verimliliğini optimize etmeye yönelik öneriler sunmaktadır. Gelecek araştırmalarda, daha büyük veri kümeleri ve ek değişkenler kullanılarak daha kapsamlı modellemeler yapılabilir.

Anahtar kelimeler: Manda sütü, Net kâr, Veri madenciliği algoritmaları, Iğdır ili, Türkiye

INTRODUCTION

Buffaloes are more resistant to natural conditions and diseases than cattle, and they make much better use of pastures and sub-forest pastures, and they can easily convert low-quality feeds into meat and milk, and thus, they are important in terms of encouraging sustainable agricultural production by allowing low-cost animal products to be obtained (Becskei et al., 2020). Buffalo milk provides a safe source of high-quality nutrients and enables the production of valuable products for healthy nutrition, and it is more advantageous than cow's milk in terms of its physicochemical, compositional and sensory properties, and stands out in terms of nutrition and health (Mane and Chatli, 2015). Buffalo milk has complete proteins with high biological value and contains all the essential amino acids that the human body needs (Khedkar et al., 2016), and it is very suitable for the production of products such as butter and cream because it contains less water and more fat compared to cow's milk (Pudja et al, 2008). Buffalo cheese is very valuable with its color and texture, and the famous Italian cheeses Mozzorella and Borelli are made from buffalo milk (Park and Haenlein, 2008; Guo and Hendricks, 2010). Buffalo meat is preferred because it has low fat and cholesterol, and buffalo skin is preferred because it is thick (Sarıözkan, 2011). While the world buffalo population, which was 88321107 head in 1961, increased by 132% to 205141830 head by 2022, in the same years, the buffalo population in Turkey decreased by 85% from 1140000 head to 171835 head (FAO, 2022). Although there are studies on buffalo breeding, its importance, meat and milk quality in Turkey (Atasever and Erdem, 2008; Sarıözkan, 2011; Yılmaz et al., 2011; Toparslan and Mercan, 2018; Konca and Yılmaz Adkinson, 2021; Yılmaz Adkinson and Konca, 2021), there is no study on the reasons for the decrease in the number of buffalo in Turkey, and this situation shows that the importance of buffalo breeding and buffalo products on farms in Turkey is not sufficiently understood. In Turkey, the total milk production in 2022 is 21563490 tons, and only 0.2% (43588 tons) of this amount belongs to buffalo milk, while 0.65% (15386 tons) of the total red meat production amount of 2384047 tons in 2023 belongs to buffalo meat (TÜİK, 2023). The world buffalo milk yield per animal is 2022 kg, and the first three places are Iran 2844 kg, Pakistan 2298 kg and India 2205 kg, while Turkey ranks 15th with 597 kg. As of 2022, the world buffalo meat yield average is 247 kg per animal, while the first three places are Malaysia 450 kg, India 368 kg and Egypt 330 kg, while Turkey ranks 9th with 218 kg (FAO, 2022). Turkey is below the world average in terms of both buffalo milk yield and buffalo meat yield. The annual inflation rate of around 72% in Turkey in 2022 compared to the previous year (TÜİK, 2022) also increases the input prices of agricultural products. Low yield on the one hand and increasing input prices on the other hand necessitate taking some measures to work more profitably in buffalo milk production and determining the factors affecting profitability.

On the other hand, data mining, which is used to develop appropriate models for determining the factors affecting the milk yield of animals and selecting more productive animals, enables the emergence of hidden patterns in the data for a better understanding of the data relationship, as well as enabling high resource use efficiency and sustainable profitability in livestock production systems (Balhara et al., 2021). The aim of this study is to determine the factors affecting the profitability in buffalo milk production and to reveal the measures to be taken to obtain more profit from buffalo milk production. For this purpose, the performances of the models used in Data Mining were tested and the model that best explains the factors affecting the profitability in buffalo milk production was tried to be determined. In this context, the following hypotheses were established;

Hypothesis 1:

H_0: There is no relationship between the determined factors and profitability in buffalo milk production.

H_1: There is a relationship between the determined factors and profitability in buffalo milk production.

Hypothesis 2:

H_0: There is no difference between Data Mining Model Performances in determining the factors affecting profitability in buffalo milk production.

H_1: There is a difference between Data Mining Model Performances in determining the factors affecting profitability in buffalo milk production.

MATERIALS AND METHODS

Study Area

Igdir province, located 10 km away from Ararat Mountain, is on the easternmost border of Turkey with 3 neighboring countries of Armenia, Nakhchivan and Iran (Figure 1). Igdir is located between 390 55' latitude and 440 03' longitude and is known as 850 m above sea level.

Figure 1. The location of Igdır province in Türkiye

The distribution of buffalo numbers is shown in Table 1. The central district accounts for 40.64% of the total buffalo numbers in the province, while Aralık and Karakoyunlu districts have 29.50% and 29.86%, respectively. In contrast, Tuzluca district has no buffalo, suggesting that the conditions or resources in this area may not be suitable for buffalo farming.

Table 1. Data on Buffalo Number in Iğdır province (2023)

District	Number of Buffalos (Head)	%
Center	562	40.64
Aralık	408	29.50
Karakoyunlu	413	29.86
Tuzluca	0	0.00
Igdir Province Total	1383	100.00
Türkiye Total	161749	-

Sampling Method and Data Collection

The data obtained from the survey conducted with face-to-face interviews with 92 buffalo-breeding farms in Igdir province is the main material of this study. The survey study was conducted between September to October 2016 and the study covers the 2016 production period. The following sampling formula, which is included in the Simple Random Sampling Method, was used to determine the number of questionnaires used in the research (Arıkan, 2007; Yamane, 2010).

$$n = \frac{N.t^2.pq}{(N-1)D^2 + t^2pq} \quad (1)$$

n= Number of samples
N= Number of registered farms
D= Sampling error
t= Table value
p= The rate to be calculated
q= 1-p

$$n = \frac{270.1{,}96^2.0{,}1.0{,}9}{(270-1)0.05^2 + 1.96^2 0.5.0.5} = 91.68 \quad (2)$$

The distribution of surveys is shown in Table 2. The total number of surveys was distributed proportionally according to the number of members in the districts.

Table 2. Number of surveys by districts

Region	Number of members	Number of Surveys	Rate (%)
Iğdır Center	130	44	48
Aralık	84	29	31
Karakoyunlu	56	19	21
Total	270	92	100

Analytical Model

This study utilized data from 92 buffalo breeding enterprises in Iğdır Province of Turkey in 2016. The dependent variable was net profit (NP), while the independent variables were lactation year (LY), veterinary cost (VC), milking method (MM), mastitis control (MC), concentrate feed quantity (CFQ), roughage quantity (RFQ), lactation period (LP), milking time (MT), and milking interval (MI).

The data was randomly divided into a 70% training set and a 30% test set to determine the applied models' cross-validation (CV) performances. The training set was further divided into 10 folds for parameter tuning through n-fold cross-validation. This approach aimed to identify the most successful models on the training set without causing overfitting problems. In this framework, each cross-validation fold was sequentially set aside. Models, such as multivariate linear regression (LM), multivariate adaptive regression splines (MARS), artificial neural networks (ANN), and decision trees (CART) methods, were trained on the remaining data and compared based on 100 different tuning parameters. The most successful models were then evaluated on the 30% test set, and the best model was determined based on the preferred goodness of fitness criterion (RMSE).

Multivariate Linear Regression (LM)

One of the fundamental analytical methods, linear models, plays a central role in the field of applied statistics. It is widely utilized in machine learning studies, serving as a baseline to compare the performances of other machine learning models (Fox and Weisberg 2019). In addition to ordinary linear regression, such models encompass various variations such as partial least squares regression, ridge regression, and elastic nets (Kuhn and Johnson 2013). In this study, the LM method has been preferred as a fundamental reference point for evaluating the performances of other models. The general equation for LM model, which models the relationship where multiple independent variables influence a dependent variable, is expressed as follows (Eyduran et al. 2017):

$$\boldsymbol{Y = \beta_0 + \sum_{\{i=1\}}^{n} \beta_i X_i + \epsilon}$$

Where; Y is defined as the dependent variable, β_0 is expressed as the intercept, β_i is the ith parameter, X_i is the ith predictor (explanatory variable), and ε is defined as the random error.

Multivariate Adaptive Regression Splines (MARS)

The MARS algorithm, developed by Friedman (1991), is a non-parametric regression technique frequently preferred in data mining. The method is based on an effective algorithm that flexibly determines linear, non-linear, and interaction effects between response sets and predictors. The non-linearity of the model is achieved by providing various regression slopes for intervals of each predictor. The slopes of potential regression lines are determined by the connections between individual regression curves (Friedman 1991). This algorithm, which follows a two-stage process involving forward selection (first stage) and backward deletion (second stage), does not require assumptions about the distributions of variables or the functional relationship between response and predictor variables (Arthur, Temeng, and Ziggah 2020). It is important to note that the advanced transition stage may lead to overfitting problems. The advanced selection stage begins with a basic set of functions that produce the smallest training error. These functions are then iteratively added to advance the model, resulting in a more complex and sophisticated model (Weber et al. 2012). The model obtained in the forward pass stage may fit very well, but its generalization ability may be weak when exposed to a different dataset, indicating susceptibility to overfitting issues. To address these problems, the basic functions that contribute the least to the model are incrementally removed in a stepwise manner during the backward pass (Sahraei et al. 2021). Kuhn (2013) asserted that the MARS algorithm is more interpretable than complex models such as ANN. This algorithm has been extensively studied in previous research (Çelik 2019; Sahraei et al. 2021), providing detailed insights into its workings.

The foundation of the MARS (Multivariate Adaptive Regression Splines) system is based on the use of piecewise linear basis functions, as formulated by Friedman (1991):

$$\mathrm{BF1}(\mathrm{x}) = |\mathrm{x}-\mathrm{t}|_+ = \max(0, \mathrm{x}-\mathrm{t}) = \begin{cases} \mathrm{x}-\mathrm{t}, & \mathrm{x} > \mathrm{t} \\ 0, & \mathrm{x} \leq \mathrm{t} \end{cases} \ldots$$

$$BF2(x) = |t-x|_+ = max(0, t-x) = \begin{cases} \mathrm{t}-\mathrm{x}, & \mathrm{x} < \mathrm{t} \\ 0, & x \geq \mathrm{t} \end{cases} \ldots$$

Here, *t* represents the knots. The aforementioned formulations act as foundational elements for linear or nonlinear modeling aimed at estimating the function *f(x)*. The *notation* $/.|_+$ signifies the positive component. These functions are alternatively referred to as reflected pairs or mirror image functions. They can be defined for each input variable X_m based on its observed values x_{km} where *k=1,2,…,n*, as follows (Celik and Yilmaz 2018):

$$BF1 = max(0, X_m - x_{km})$$
$$BF2 = max(0, x_{km} - X_m)$$

If the dependent variable y relies on M terms, the MARS model can be formulated as shown in the following equation (Friedman 1991):

$$y = f(x) = \beta_0 + \sum_{i=1}^{M} \beta_i H_{ki}\left(X_{v(k,i)}\right) \ldots \ldots$$

Here, β_0 and β_i denote the parameters of the basis functions within the model, and the function H is defined as in the following equation (Friedman 1991):

$$H_{k,i}\left(X_{v(k,i)}\right) = \prod_{k} (-1)^k k_{ki}$$

Here $X_{v(k,i)}$ denotes the estimator corresponding to the *k*-th component of the *i*-th product. When the interaction order *K=1*, the model is additive; whereas for *K=2*, the model incorporates pairwise interactions (Celik and Yilmaz 2018; Friedman 1991).

In general, the generalized cross-validation (GCV) criterion is applied to select the best subset model. GCV is calculated as follows (Celik and Yilmaz 2018):

$$GCV = \frac{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}{\left[1 + \frac{M + d.(M-1)/2}{N}\right]^2}$$

Where, *N* represents the total number of observations, y_i is the dependent variable $\hat{y}_i$ denotes the predicted values from the MARS model, *d* is the penalty applied for each basis function included in the sub-model, and *M* indicates the total number of basis functions.

Artificial Neural Networks (ANN)

ANN were introduced to the literature for the first time in 1943 by neurophysiologist Warren McCulloch and mathematician Walter Pitts. McCulloch and Pitts (1943) introduced a simplified computational model based on the working principles of biological neurons in animal brains to perform complex calculations. This approach has since been followed by numerous different architectures, and the Multilayer Perceptron (MLP) algorithm which is preferred in this study is one of the algorithms developed within this context. The structure, composed of a combination of sensors in multiple layers, lies at the heart of the concept of deep learning. Their versatility, strength, and scalability make them ideal for overcoming large and highly complex machine-learning tasks, such as classifying billions of images (Géron 2017). This algorithm consists of many individual computation nodes connected according to various architectures. The calculations within each node are generally simple; in most cases, models lead to a binary response, but they can deliver powerful results in terms of performance (Titterington 2010). Sensors are based on artificial neurons called linear threshold units. Linear threshold units are structured in a way where each input connection corresponds to a weight, rather than a binary input-output structure. A critical component of these units is the activation function, which introduces non-linearity into the network, enabling it to capture and model complex patterns and dependencies in the data. Activation functions, such as sigmoid, ReLU (Rectified Linear Unit), and tanh, play a vital role by transforming the weighted sum of inputs into outputs that range between fixed limits. This transformation ensures that the network can solve non-linear problems and perform tasks like classification, regression, and feature extraction effectively. In multilayer

perceptrons, it consists of an input layer, one or more layers known as hidden layers, and a final layer called the output layer (Géron 2017). This method has been widely used in various studies, and explanatory information about the algorithm has been presented in previous works (Okut et al. 2013; Zhang et al. 2023).

Decision Trees (CART)

Among the non-parametric methods, tree-based models, categorized as 'divide and conquer' algorithms, operate by constructing a simple model for each region (Boehmke and Greenwell 2020). In this study, the CART algorithm developed by Breiman et. al. (1984) was preferred. In this method, capable of both regression and classification operations, the tree is constructed by progressing from the starting point to the leaf. The design of the tree places the root at the top, with the leaves representing the results at the bottom. At the root, all classifications in the initial dataset are mixed. Subsequently, the tree is developed towards the first node by employing a specific feature variable to partition the population into distinct categories (Nwanganga and Chapple 2020). For regression trees, the modeling process with the CART algorithm begins with the entire dataset. It involves searching through all values for each attribute to identify the optimal split value that minimizes the sum of squared errors by dividing the dataset into two parts. Subsequently, within each of these partitioned groups, the search continues to find the best combination of predictors and partition values that further minimize the sum of squared errors (Kuhn and Johnson 2013). Previous studies have shared detailed information about the CART algorithm (Akin et al. 2018; Faraz et al. 2021).

Explainable Artificial Intelligence Algorithms

The model with the best cross-validation value among the mentioned models was interpreted using explainable artificial intelligence algorithms, specifically variable importance plots and partial-dependence profiles.

Variable Importance (VI): Permutation-based variable importance metrics are a method for determining the significance and weight of an explanatory variable within a model. This method can be utilized to identify and exclude variables that do not impact the model predictions by comparing the importance of variables. Additionally, it can assist in determining the most critical variables and evaluating the validity of the model based on expert opinions (Biecek and Burzykowski 2021).

Partial-dependence Profiles (PD): The fundamental approach in creating partial-dependence profiles, developed by Friedman (2001), is to illustrate the impact of an explanatory variable on the expected value of a chosen prediction. For a single model, it is possible to create a general profile using all observations in a dataset or specific subsets with multiple profiles. These profiles assist in making complex black-box models more understandable and can also be used to compare different models. They succinctly summarize the effect of a particular explanatory variable on the dependent variable, making explanations more comprehensible (Biecek and Burzykowski 2021).

Application process of machine learning models

To evaluate the cross-validation (CV) performance of the models employed, the dataset was divided randomly into two parts: a 70% training set and a 30% test set. Before training, the data underwent pre-processing to eliminate variables with near-zero variance, linearize them using the Yeo-Johnson method (2000), normalize them by standard deviation, and create dummy variables for categorical variables.

To optimize the models, a range of 100 different combinations of fine-tuning parameters were tested on the training set using 10-fold cross-validation with 5 repetitions. The model with the most successful cross-validation value from the candidate models was selected for the next stage. Fine-tuning was performed using a standard grid search within the given parameter range. It is important to note that the LM algorithm has not undergone fine-tuning. The MARS algorithm's grid has a range of values for num_terms, from 2 to 5, and for degree, either 1 or 2. Additionally, it offers a selection of prune_method values, including 'backward', 'none', 'exhaustive', 'forward', or 'seqrep'. The algorithm was developed using 'cv' values.

The grid for fine-tuning ANN comprises a range of values for several parameters, including hidden units (hidden_units) from 1 to 10, a logarithmic penalty between log10(-10) and log10(0), epoch values (epochs) between 5 and 500, and a logarithmic learning rate (learn_rate) ranging from log10(-3) to log10(-0.5). The grid of the CART algorithm is built by utilizing the cost-complexity parameter (cost_complexity) with logarithmic values that range from log10(-10) to log10(-1), tree depth (tree_depth) that ranges from 1 to 15, and minimum node size (min_n) that ranges from 2 to 40.

Goodness of fit criteria were calculated on the test sets of the models with the most successful CV values on the training sets. Performances of the models were measured with goodness of fit criteria. Below are the formulas for the preferred goodness of fit criteria (Willmott and Matsuura 2005; Eyduran et al. 2017; Çelik 2019):

Coefficient of determination (R^2):

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_i - \hat{Y})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2} \quad (3)$$

Root-mean-square error (RMSE):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y - \hat{Y})^2} \quad (4)$$

Mean absolute error (MAE):

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left(\left|Y - \hat{Y}\right|\right) \quad (5)$$

Mean absolute percentage error (MAPE):

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Y - \hat{Y}}{Y}\right| . 100 \quad (6)$$

n is the number of cases in a set, Y is the real value of an output variable (NP), $\hat{Y}$ is the predicted value of an output variable (NP).

Models are ranked based on their measured RMSE values. The model with the lowest RMSE value for the test data set and with no significant difference between the RSME values of the training and test sets was accepted as the most successful model.

Variables Used in the Models

Dependent and independent variables in the data set are given in Table 3.

Table 3. Variables used in the models

Dependent Variable	**Type**	**Explanation**
Total net profit (TNP)	Continuous	$
Explanatory variables	**Type**	**Explanation**
Lactation year (LY)	Continuous	Year
Veterinary cost (VC)	Continuous	$
Milking method (MM)	Dummy	1: By Hand, 2: By Machine
Mastitis control (MC)	Dummy	1: Yes, 2: N0
Concentrated feed quantity (CFQ)	Continuous	Kg
Roughage feed quantity (RFQ)	Continuous	Kg
Lactation period (LP)	Continuous	Day
Milking time (MT)	Continuous	Minute
Milking interval(MI)	Continuous	Hour

Software Used

In this study, the R statistical environment (ver. 4.1.3) (Anonymous 2022) was preferred. The modeling was conducted through the tidymodels framework (ver. 1.1.0) (Kuhn and Wickham 2020). The LM model was trained using the R base library; the CART model was trained with the rpart package (ver. 4.1.19) (Therneau and Atkinson 2022). The MARS modeling was performed using the earth package (ver. 5.3.2) developed by Milborrow (2011). The ANN model was trained using the brulee package (ver. 0.2.0), developed for using the pytorch module in R (Kuhn and Falbel 2022). Variable importance metrics and partial dependence profiles for the models were created using the DALEX package (ver. 2.4.3) developed by Biecek (2018) and the DALEXtra package (ver. 2.3.0) created by Maksymiuk et al. (2020).

RESULTS AND DISCUSSION

As a result of the analyses, the most suitable models were determined based on their cross-validation RMSE values (CVRMSE). Among the 100 candidate models trained for each model, the fine-tuning parameters of the most successful models were identified. For instance, the MARS model had num terms = 4, prod degree = 1, prune method = 'cv' (CVRMSE = 162.11). For ANN, the parameters were hidden units = 8, penalty = 0.0408, epochs = 370, learn rate = 0.196 (CVRMSE = 218.18). The CART model had parameters cost complexity = 0.00209, tree depth = 15, min_n = 29 (CVRMSE = 218.11). The LM model had no fine-tuning parameters (CVRMSE = 222.17).

According to the goodness of fit criteria presented in Table 4, the MARS Model algorithm demonstrated the highest level of success with the lowest RMSE values in the test dataset. The performance values of the MARS model in the training set (RMSE: 160.661) and test sets (RMSE: 162.445) are not significantly different, which suggests that the model is not overfitting and is generalizable.

Table 4. Goodness-of-fit values

Model	Dataset	R^2	RMSE	MAE	MAPE
LM	train	0.639	206.143	148.374	15.258
	test	0.762	173.602	129.437	11.698
MARS	train	0.781	160.661	124.942	12.622
	test	0.776	162.445	131.771	11.823
MLP	train	0.716	184.065	135.921	13.680
	test	0.774	172.452	120.489	10.915
CART	train	0.676	195.391	146.404	15.296
	test	0.674	196.909	151.554	14.510

Upon analysis of the variable importance rankings of the models together (refer to Figure 2), it is clear that the two most significant variables affecting Net Profit in all models are LY and LP. When evaluating the models based on the variables affecting Net Profit, it is evident that only LY and LP have a significant impact. The ANN model, however, shows that CFQ and MC also have a partial effect, while in the CART and LM models, only CFQ has a partial effect. Nevertheless, it is important to note that removing these variables, as well as any variables other than LP and LY, does not affect the model performance.

It should also be noted that the Linear Regression (LM) model in this study was utilized solely for the purpose of comparing its performance with other machine learning models. As a result, the assumptions typically required for linear regression, such as normality, homoscedasticity, independence of residuals, and absence of multicollinearity among predictors, were not evaluated or validated. This approach was adopted to focus on the predictive accuracy and comparative performance of the models rather than ensuring the strict adherence of LM to its theoretical assumptions.

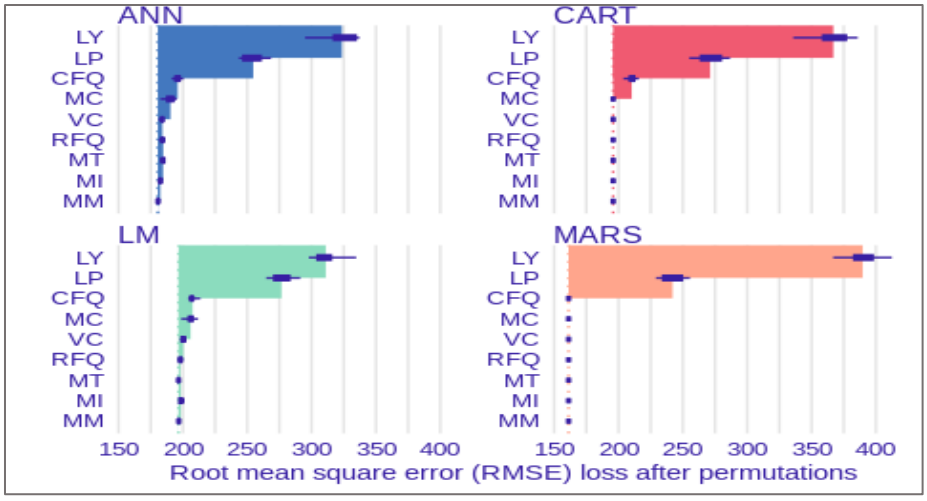

Figure 2. Variable importance plots generated for ANN, CART, LM, MARS models

In parallel with the results obtained in the variable importance plots, according to the partial-dependence profiles (Figure 3), it is observed that the changes in the variables CFQ, MI, MT, RFQ, VC have no effect on the predicted value of the MARS model (net profit). However, it was observed that the LY variable had a positive effect on total net profit up to a value of approximately 7.0, but a negative effect after this value. This suggests that in order to prevent the decrease in net profit, buffalo breeders should sell the buffaloes after the 7th lactation. There are very limited studies on the effect of lactation year on milk yield; Kaygısız (1999) stated that the highest yield from domestic buffalos was obtained in the 6th lactation and buffalos giving birth in the autumn season started lactation with a higher yield. Şahin et al. (2024) reported that the highest milk yield was obtained in Anatolian buffalos in the 3rd lactation between 90-120 days.

Call: earth(formula=y~., data=bake(prep(normal), train_data), pmethod="exhaustive", degree=1, nk=5)
coefficients
(Intercept) 1646.6552
h(1.49075-LY) -275.2942
h(LY-1.49075) -543.2853
h(0.372269-LP) -145.7062
h(LP-0.372269) 108.0481

Selected 5 of 5 terms, and 2 of 9 predictors (pmethod="exhaustive") Termination condition: Reached nk 5 Importance: LY, LP, VC-unused, CFQ-unused, RFQ-unused, MT-unused, Number of terms at each degree of interaction: 1 4 (additive model) GCV 32206.9; RSS 3819596; GRSq 0.7332048; RSq 0.7638881.

Based on the estimated coefficients obtained from the MARS model, the fitted equation can be expressed as follows:

$$\hat{y} = 1646.6552 - 275.2942 \cdot h(1.49075 - LY) - 543.2853 \cdot h(LY - 1.49075) - 145.7062 \cdot h(0.372269 - LP) + 108.0481 \cdot h(LP - 0.372269)$$

Where $h(z) = max(0, z)$ represents the positive part hinge function, and *LY* and *LP* are predictor variables included in the model.

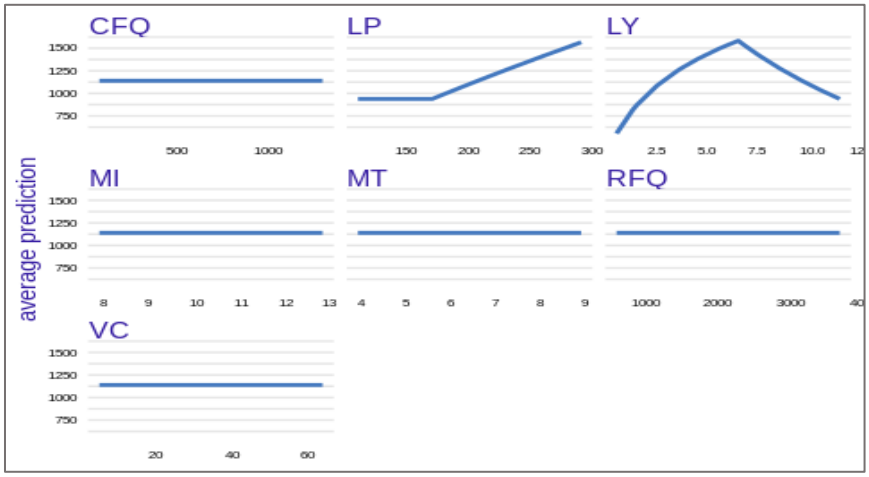

Figure 3. Partial-dependence profiles of the MARS model

The value of approximately 175 was determined by visually inspecting Figure 3, which presents the Partial Dependence Profiles of the MARS model. From this graph, it can be observed that increases in the LP variable have no significant effect on net profit until reaching around 175 days, after which net profit begins to increase linearly. Therefore, buffalo producers are advised to take measures to extend the lactation period beyond this threshold. While Kaygısız (1999) found the highest productive lactation period to be 124 days, he recommended planning optimum feeding and management programs to extend this period. Şekerden and Küçükkebapçı (1999) found that milk yield decreased after 210 days of lactation in Anatolian buffalos. Galsar et al. (2016) found the lactation period of Meshana Buffalo in India to be 298 days, Soysal et al. (2018) found the lactation period of Anatolian buffalo to be 231 days, Yılmaz Adkinson and Konca (2021) compared the lactation periods and milk yields of different buffalo breeds in the world and found that lactation periods varied between 210-350 days, Yenilmez et al. (2022) found the lactation period of Italian Mediterranean buffalos to be 247 days.

Luna-Polomera et al. (2021) compared Mixed nonlinear models in Murrah buffalos for 3 lactation periods (180 days, 210 days and 240 days) and concluded that the model with the highest efficiency and best fit at 180 days was WOOD. In addition, regarding water buffalo breeding and increasing profitability, Sweers et al. (2014) found that calf-calf interval had the highest impact on total economic performance in reproductive performance in water buffalo breeding in Germany, Sabia et al. (2015) found that the demand for water buffalo dairy products was increasing in many countries, more efforts were needed in the genetic evaluation of water buffalo populations and that one of the biggest challenges faced by the sector was low profitability. Işık and Gül (2016) reported that feed costs affect profitability the most in water buffalo breeding in Muş province and that farmers should be informed about modern techniques so that producers can earn more by increasing milk yield. Aydoğdu and Şahin (2022) stated that pure breeding and breed development activities should be expanded to increase meat and milk yield in buffalo breeding in Turkey.

CONCLUSION

This study has provided significant insights into the factors influencing profitability in buffalo milk production, leveraging advanced data mining algorithms to identify key determinants. Among the models tested, MARS model demonstrated superior performance in predictive accuracy and robustness, based on cross-validation and goodness-of-fit criteria. The analysis identified lactation year and lactation period as the most critical variables affecting net profit, with profitability reaching its peak during the seventh lactation year and increasing linearly for lactation periods exceeding 175 days. These findings emphasize the importance of implementing evidence-based management strategies in buffalo production systems.

The threshold of 175 days for the lactation period is particularly significant, as it marks the point beyond which net profit begins to increase more substantially. This suggests that efforts to extend the lactation period beyond this duration can directly enhance profitability. Practically, buffalo producers should focus on nutritional, health, and environmental management practices that support longer lactation cycles. By targeting this critical period, producers can optimize milk yield and improve overall economic returns, making the 175-day lactation period a key performance indicator in sustainable buffalo farming.

This research also underscores the utility of data mining methodologies in agricultural studies, offering a robust framework for analyzing complex relationships between variables and profitability. The results contribute to the growing body of knowledge on livestock management and provide actionable recommendations for improving production efficiency. Future studies should seek to validate these findings across diverse geographical and management contexts while exploring additional variables to further refine strategies for enhancing productivity and profitability in buffalo farming systems.

Declaration of interests

There is no conflict of interest among the authors of the article.

Author Contributions

***Köksal KARADAŞ*:** Conceptualization, data curation, formal analysis, investigation, methodology, writing and review.
Osman Doğan BULUT: Formal analysis, investigation, methodology, writing, review and editing.
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Original Article

Forecasting the Power Output of Photovoltaic Systems Using Ant Colony Optimization and Determining the Optimal Time Interval for Agricultural Use

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ABSTRACT

The rapid increase in global energy demand, driven by industrialization, population growth, and technological advances, has emphasized the importance of the transition to renewable energy sources. In addition, renewable energy, especially photovoltaic (PV) systems, has become a widespread energy source in agricultural applications to meet the energy needs in agricultural irrigation. However, the efficiency of PV systems varies depending on meteorological and environmental factors such as solar radiation and temperature. Therefore, predictability of energy production is a critical requirement for the effective operation of irrigation systems. In this study, the Ant Colony Optimization (ACO) algorithm is implemented to estimate the power output of PV systems using historical solar radiation, temperature, and actual power production data. Inspired by the foraging behavior of ants, the ACO algorithm optimizes the estimation process by iteratively refining the solutions based on pheromone trails and adaptive learning. The proposed method is evaluated using a case study on a solar power plant located in the Central Anatolian region of Türkiye. The accuracy of the model is evaluated by comparing the predicted values with the actual measurements at various time periods including hourly, daily, weekly, monthly and seasonal forecasts. The results show that the ACO based forecast model provides high accuracy in predicting the PV power output, with the Mean Absolute Percentage Error (MAPE) values improving as the forecast period increases. The findings of this study suggest that ACO is a robust and efficient optimization technique to improve PV power forecasting. The proposed model provides strategic information that can be used in energy planning of agricultural irrigation systems with high accuracy.

Key words: Photovoltaic Systems, Power Prediction, Ant Colony Optimization, Renewable Energy, Solar Radiation.

Karınca Kolonisi Optimizasyonu ile Fotovoltaik Sistemlerin Güç Çıkışının Tahmini ve Tarımsal Kullanım İçin En Uygun Zaman Aralığının Belirlenmesi

ÖZ

Küresel enerji talebindeki hızlı artış, sanayileşme, nüfus artışı, teknolojik ilerlemeler tarafından yönlendirilen, yenilenebilir enerji kaynaklarına geçişin önemini vurgulamıştır. Bunun yanında, tarımsal sulamada enerji ihtiyacını karşılamak için yenilenebilir enerji, özelliklede fotovoltaik (PV) sistemler aracılığıyla tarımsal uygulamalarda yaygınlaşan bir enerji kaynağı haline gelmiştir. Ancak, PV sistemlerinin verimi, solar ışınımı ve sıcaklık gibi meteorolojik ve çevresel faktörlere bağlı olarak değişkenlik göstermektedir. Bu nedenle, sulama sistemlerinin etkin çalışması için enerji üretiminin öngörülebilir olması kritik bir gerekliliktir. Bu çalışmada, PV sistemlerinin güç çıktısını tahmin etmek için Karınca Kolonisi Optimizasyonu (KKO) algoritması, geçmiş solar ışınımı, sıcaklık ve gerçek güç üretim verileri kullanılarak uygulanmıştır. KKO algoritması, karıncaların yiyecek arama davranışından esinlenerek, feromon izleri ve adaptif öğrenme temelinde çözümleri yinelemeli olarak rafine ederek tahmin sürecini optimize eder. Önerilen yöntem, Türkiye'nin Orta Anadolu bölgesinde bulunan bir

güneş enerjisi santrali üzerine yapılan bir vaka çalışması kullanılarak değerlendirilmektedir. Modelin doğruluğu, saatlik, günlük, haftalık, aylık ve mevsimsel tahminler dahil olmak üzere çeşitli zaman dilimlerinde tahmin edilen değerlerin gerçek ölçümlerle karşılaştırılmasıyla değerlendirilir. Sonuçlar, KKO tabanlı tahmin modelinin PV güç çıktısını tahmin etmede yüksek doğruluk sağladığını, Ortalama Mutlak Yüzde Hatası (OMYH) değerlerinin tahmin süresi uzadıkça iyileştiğini göstermektedir. Bu çalışmanın bulguları, KKO'nun PV güç tahminini geliştirmek için sağlam ve verimli bir optimizasyon tekniği olduğunu önermektedir. Önerilen model, tarımsal sulama sistemlerinin enerji planlamasında yüksek doğrulukla kullanılabilecek stratejik bilgiler sunmaktadır.

Anahtar kelimeler: Fotovoltaik Sistemler, Güç Tahmini, Karınca Kolonisi Optimizasyonu, Yenilenebilir Enerji, Solar Işınım.

INTRODUCTION

Energy demand is rapidly increasing due to technical developments, industrial operations and the continuous increase in the global population. As a result, electrical energy has emerged as a vital element of contemporary life with an increasing demand. Turkey, similar to the global trend, receives a significant portion of its energy requirements from fossil fuels. The harmful effects and ecological consequences of fossil fuels on sustainability lead to significant environmental problems such as global climate change, increasing temperatures and glacial melting.

Agricultural irrigation plays a vital role in the sustainability of productivity in agricultural production, and the energy requirement of irrigation systems constitutes a significant operational cost item for farmers. Especially in arid and semi-arid climate zones, the effective operation of irrigation systems is largely dependent on energy. At this point, solar energy, which stands out among renewable energy sources, both ensures environmental sustainability and reduces the problem of access to energy in rural areas. However, the performance of PV systems varies depending on meteorological parameters such as sunshine duration, radiation intensity and ambient temperature. Therefore, it is critical to be able to accurately predict solar energy production in order to optimize the timing and capacity planning of agricultural irrigation systems.

Greenhouse gases emitted especially as a result of burning fossil fuels contribute significantly to critical environmental problems such as global warming and climate change. This scenario disrupts the balance of ecosystems by affecting natural habitats, sea levels and air quality. As a result, it is imperative to switch to renewable energy sources to ensure a reliable, environmentally friendly and sustainable energy future. Renewable sources such as wind, solar and hydroelectric energy hold significant promise for environmental sustainability and serve as an alternative to limited fossil fuel resources.

The Global Status Report (Members, 2023) shows that recent global public opinion polls reveal an increasing interest in renewable energy sources. In recent years, solar energy has received the most attention and has the largest capacity expansion among renewable energy sources. The increasing interest is due to the numerous benefits provided by solar energy. Solar energy is an abundant and inexhaustible source that does not create air pollution. Its transportation costs are very low, which distinguishes it from alternative energy sources (Members, 2023). In recent years, solar energy has become the fastest growing renewable energy source in Türkiye (Figure 1).

In light of sustainability goals and increasing environmental problems, environmentally friendly energy production is very important today. As a result, solar energy is emerging as a more ecologically sustainable approach to electricity generation. The sun acts as a source of heat and light, generating energy by emitting equal amounts of light in all directions. These features make solar energy a clean, silent, inexhaustible and reliable alternative to other energy sources.

The high cost and low efficiency of photovoltaic panels are the main reasons why solar energy is not yet a major energy source. However, current research and technology developments have led to a significant decrease in solar module prices. This has made solar energy more accessible. In particular, since 2020, photovoltaic module costs have decreased by more than 40% (Irena, 2020). This decrease and its continuation are expected to make solar energy more economically viable and expand its applications.

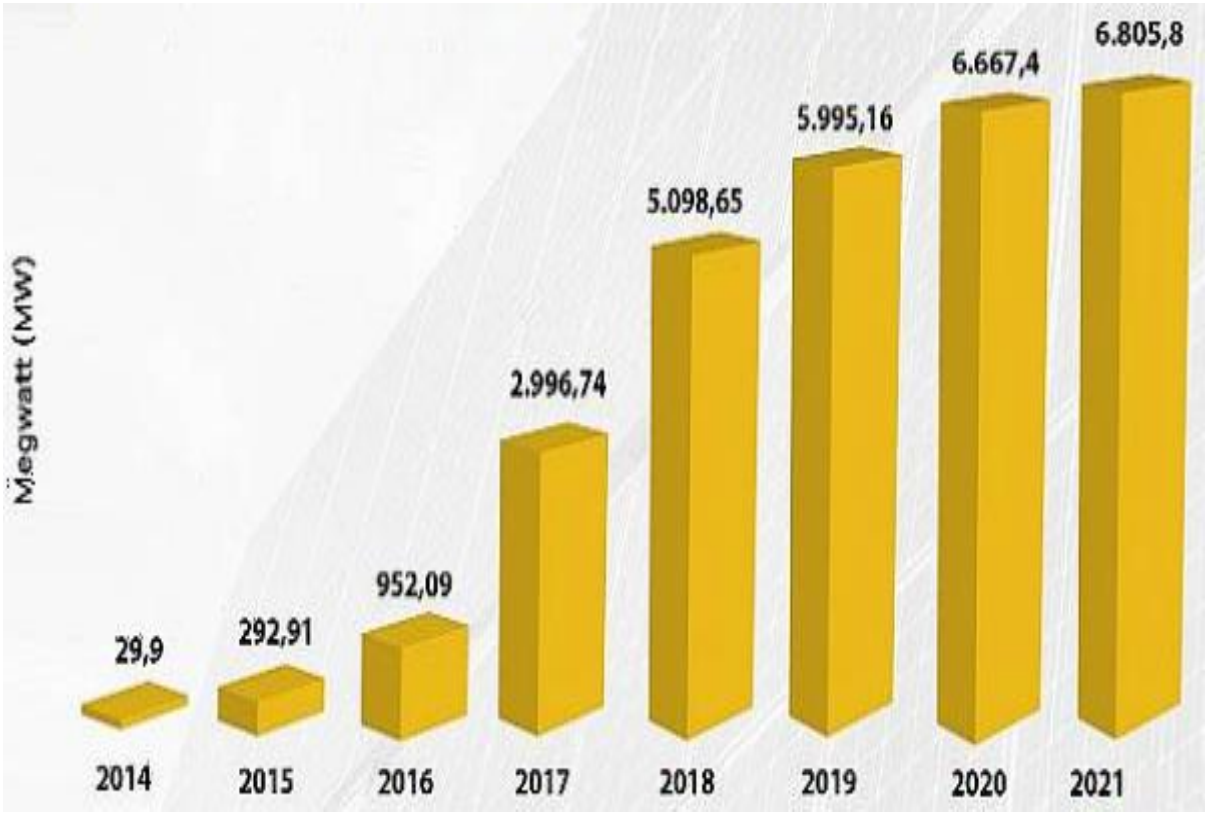

Figure 1. Total installed capacity of solar energy in Türkiye by years.

Solar radiation continuously serves as the main energy source for photovoltaic systems; therefore, accurate assessment of solar radiation is essential for the operation of power grids and photovoltaic systems. A review of similar studies in the literature reveals various methodologies and strategies used in photovoltaic power assessment. Mandal et al. proposed a hybrid artificial intelligence (AI) and wavelet transform (WT) method to estimate PV output power. Wind turbulence greatly affects the time series data of photovoltaic generation, but AI solutions reduce photovoltaic variations (Mandal et al., 2012). Zhang et al. collected data using panel temperature, average temperature, relative humidity, and solar radiation. The genetic algorithm-based backpropagation ANN prediction model produced RMSE at 0.11 MW and MAPE at 3.31 MW in daily predictions, as well as the proposed k-means result (Zhang et al., 2021). Netsanet et al. determined the MAPE values as 22.31 MW and RMSE values as 0.71 MW for the long-short-term memory-based neural network model. In hourly photovoltaic power prediction, the 2NN model based on variational mode decomposition and ant colony optimization outperformed the ANN models based on genetic algorithm and ant colony optimization (Netsanet et al., 2022). Visser et al. studied multiple machine learning models for photovoltaic power prediction using historical photovoltaic power data and meteorological projections (Visser et al., 2019). Daily precipitation, relative humidity, air temperature, wind direction, active energy, and global and scattered horizontal solar radiation data were used for a temporal convolutional network model developed by Zhang et al. (Zhang et al., 2021). Liang et al. discovered that weather uncertainty and error rates increase as the forecast period increases and proposed a combination of decision trees, an improved whale bat optimization algorithm, and least squares support vector regression (Liang et al., 2023). Huang et al. presented a weather forecast-based PV power forecast using K-means clustering to categorize historical production data and a long-short memory neural network with attention mechanism to improve power forecasting (Huang et al., 2019).

The power generation of photovoltaic systems may vary depending on environmental conditions. The performance of photovoltaic systems is subject to daily and seasonal fluctuations due to environmental factors such as solar radiation, seasonal changes, and weather conditions. These differences pose a significant obstacle, especially for the planning and installation of large-scale photovoltaic systems. Changes in power generation affect the decision-making processes of large-scale systems, and strategic planning should be made considering these changes. Therefore, it is very important to estimate the power production in advance so that the systems can be installed in suitable areas and capacities.

This study aims to estimate the power production to be obtained from PV systems with a model based on the ACO algorithm. The performance of the model at hourly, daily, weekly, monthly and seasonal levels was

evaluated and error rates were calculated. In addition, it is aimed to provide strategic information in planning the most appropriate irrigation scheduling in agricultural irrigation with the power output estimation of PV systems.

MATERIALS AND METHODS

PV Model

PV systems are semiconductor devices used to convert solar energy directly into electrical energy. PV systems are becoming increasingly important among renewable energy sources, especially in today's world where energy demand is increasing and dependence on fossil fuels must be reduced, by offering environmentally friendly, sustainable and economical solutions. Photovoltaic panels, which usually consist of silicon-based cells, use the photovoltaic effect to convert solar radiation into electrical energy.

The physical and environmental conditions that affect the panel's electricity production can be modeled with mathematical expressions for PV models. A photovoltaic cell produces electricity based on solar radiation (Hossain & Mahmood, 2020). Sunlight intensity, module efficiency, temperature, and the orientation and tilt of the panel are among the many factors that affect the performance of photovoltaic systems. Maximum power point (MPP) tracking technologies, inverters and control systems ensure that the system always reaches its optimum performance level. This maximizes energy production and increases the efficiency of the system.

Advantages:

• Renewable Energy Source: Solar energy is an unlimited source.
• Environmentally Friendly: Generates electricity without carbon emissions.
• Low Operating Costs: Systems are generally long-lasting and have low maintenance costs.

Disadvantages:

• High Initial Cost: Installation and initial investment costs can be high.
• Weather Dependent: Production may decrease on cloudy or rainy days.
• Area Requirement: High power production requires a large area.

PV output power can be affected by many factors. Panel structure, natural events and panel location are among the many factors that can affect output power and efficiency. The most important factors affecting PV output power, such as solar radiation, temperature, number of panels and efficiency, are explained below.

Solar Radiation (W/m2): Solar radiation measured in W/m2 directly affects the energy output of photovoltaic panels. Under standard test conditions (STC), solar radiation is expected to be 1000 W/m². However, daily variations, cloud cover and geographical location can affect actual radiation values (HassanzadehFard et al., 2020).

Temperature (T): The efficiency of solar panels depends on temperature. Environmental variables such as temperature and radiation significantly affect the output power of the photovoltaic module. Rising temperatures can reduce the voltage of solar cells and thus reduce the overall output. Panels reach optimum power at 25°C; however, efficiency decreases with increasing temperatures. The temperature coefficient (%β) affects this phenomenon. This varies between -0.3% and -0.5% per degree for the majority of panels (Singh et al., 2020).

Number of Panels (N): The number of panels used in the system affects the overall power output. Various calculations are made using series or parallel configurations. Series-connected panels increase the voltage while maintaining a constant current. Parallel-connected panels increase both current and voltage. Equation 1 is used to determine the output power of the photovoltaic module (Sultan et al., 2021):

$$P_{PV} = \eta \times A \times G \tag{1}$$

In this context, η represents the overall efficiency of the photovoltaic panel, A denotes the area of the photovoltaic panel, and G signifies the solar radiation.

Efficiency (η): In photovoltaic systems, energy losses occur due to factors such as inverters, wiring, thermal losses and pollution. The overall efficiency of photovoltaic panels is determined using Equation 2 (Sultan et al., 2018):

$$\eta = \eta_r \times \eta_t \times \left[1 - \beta_T \times (T_c - 25) - \beta_T \times I_r \times \left(\frac{T_{nom}-20}{800}\right) \times (1 - \eta_r \times \eta_t)\right] \tag{2}$$

In this context, η_r denotes the reference efficiency, while η_t represents the highest power point efficiency. β_T denotes the temperature coefficient. T_c denotes the cell temperature, while T_{nom} signifies the nominal cell temperature.

The output power of photovoltaic systems is directly affected by environmental conditions and system components. In fact, shadow, pollution, and maintenance conditions can reduce efficiency. As a result,

temperature effects and losses should be taken into account during system design. To achieve maximum power, efficient panels should be selected, optimum panel positioning should be provided, and high-efficiency inverters should be used.

Ant Colony Algorithm (ACO)

ACO is a metaheuristic optimization technique derived from the behavior of ant colonies in nature in finding food and returning to their nests. This approach determines the optimal solution by a collection of virtual "ants" that randomly traverse the solution space. Ants determine their routes within the solution space using chemical agents known as "pheromones". The density of pheromones fluctuates according to the quality of these routes, and over time, the evaporation of these trails reduces the influence of less preferred channels (Dorigo & Stützle, 2019).

After this procedure is completed, routes with higher pheromone concentrations represent superior solutions, which leads to a preference for these routes among other ants. The cooperative action of ants facilitates the discovery of superior and more efficient solutions within the solution space (Blum, 2005).

Utilization of Ant Colony Optimization for Estimating Photovoltaic Power Output

Ant Colony Algorithm is an effective technique especially for complex and multivariate optimization challenges. This paper describes the application of ACO in predicting the power output of photovoltaic systems (Xia et al., 2024).

Solution Space: The output of photovoltaic power depends on various factors such as solar radiation, temperature, humidity, wind speed and panel efficiency. These parameters are related to the solution space that each ant moves in the ACO algorithm. The ants try to optimize these variables and determine the parameters that will give the most accurate power estimate (Titri et al., 2017).

Pheromone System and Fitness Function: Ants use pheromones to indicate the path they follow in the solution space; this depends on the degree of error between the estimated and actual power outputs. The fitness function is represented by error, such as Mean Absolute Error (MAE) or MAPE. Ants prefer paths that produce minimum error values.

Iterations and Optimization: Iterations and Optimization: ACO continues until an optimal solution is determined by an iterative procedure. Over time, pheromones start to attract paths closer to the optimal solution. As a result, an optimized model is created that calculates the power output of the photovoltaic system, taking into account solar radiation, temperature, and other environmental variables. The process flow of ACO is shown in Figure 2.

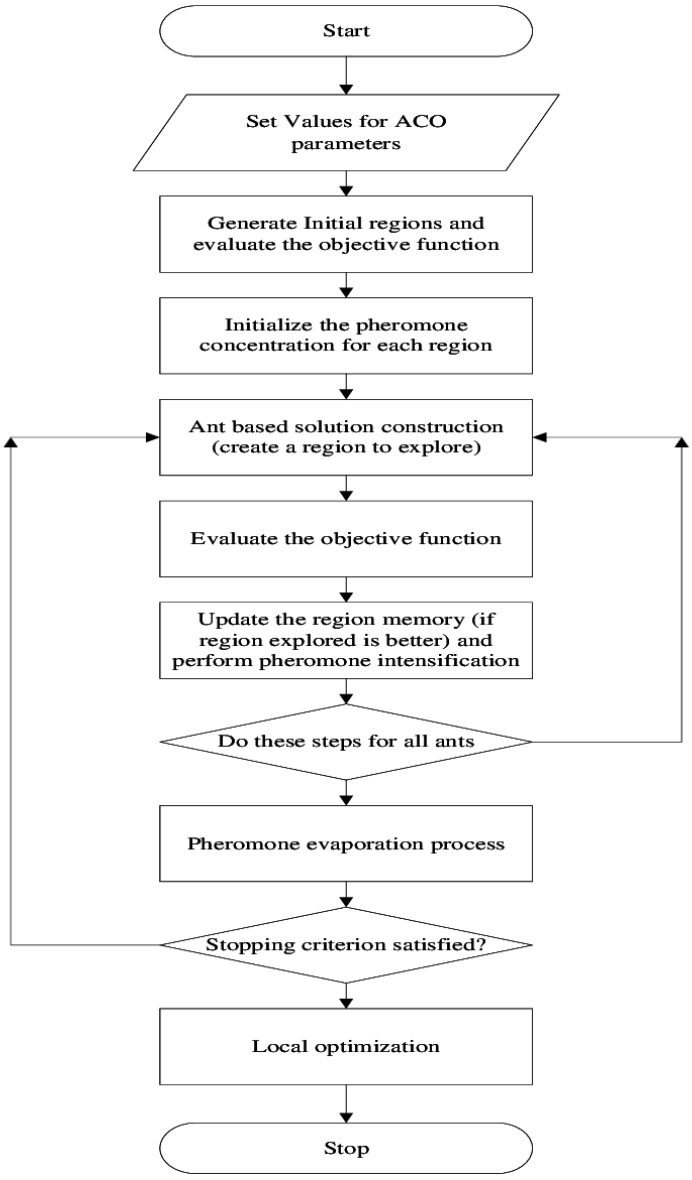

Figure 2. Ant Colony Algorithm (Nandihal et al., 2022).

RESULTS AND DISCUSSION

In this study, an ACO model is used to estimate the power generation of PV systems using a case study of a solar power plant located in the Central Anatolia Region of Türkiye. In order to evaluate the effectiveness of the model, the actual measured data and predicted power values of the PV system are evaluated. The effect of the output power on solar radiation and temperature is analyzed and the predicted results are compared with the actual values of the photovoltaic system. According to the power output estimates of the PV systems, it is aimed to provide preliminary information on the most effective and efficient planning of irrigation in which hours, days, months and seasons to meet the energy needs in agricultural irrigation. The analyses are conducted in multiple time intervals and the correlation between the produced results and the actual results is evaluated using graphical representations. In order to verify the precision of the estimates, the MAPE values are calculated and shown in a comparable manner. The MAPE equation is shown in Equation 3.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{P_{Real}-P_{Prediction}}{P_{Real}}\right| * 100 \quad (3)$$

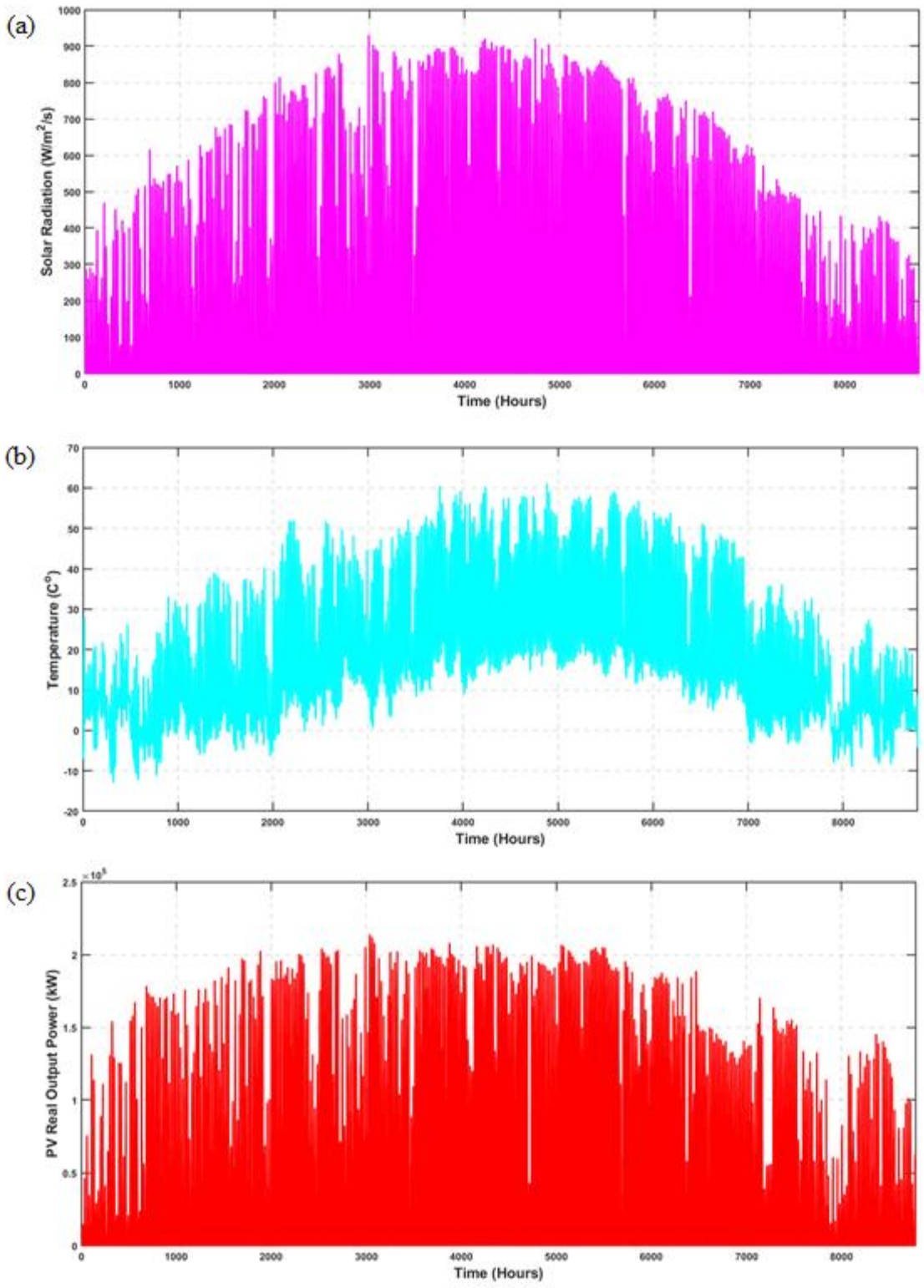

Figure 3. One year data (a) Solar radiation (b) Temperature (c) Real power output

Five hundred watt photovoltaic panels were used in the study. The efficiency of the panels was 22%. Annual solar radiation, temperature and real power production variables were used to evaluate the power of the photovoltaic panels.

Figure 3 shows the daily solar radiation, temperature and real power values for panels (a), (b) and (c) during a year, respectively. Figure 3(a) shows the daily variation in solar radiation. Temporal variations in solar radiation directly affect the energy production capacity of photovoltaic panels.

Figure 3(b) shows the daily temperature fluctuations. Temperature significantly affects the efficiency of photovoltaic panels. An increase in temperature usually results in a decrease in panel efficiency.

Figure 3(c) shows the daily real power output of photovoltaic panels. The change in power production with solar radiation and temperature can be easily seen here. In order to evaluate the efficiency of the forecast model, the forecast power levels were juxtaposed with the real measured values over several periods. The analyses were carried out daily, weekly, monthly and seasonally over a year. In addition, July, the sunniest month with the highest power output of the year, was compared with July 7, the month with the highest production intensity in July. Energy production increases on days with high solar radiation, allowing irrigation systems to operate for longer and more powerfully. However, the efficiency of PV panels decreases as the temperature increases. This situation reveals the need to pay attention to energy efficiency, especially in summer months, in irrigation processes.

Figure 4 shows the graph between the real power measured hourly and the predicted power over a year. The hourly analysis for one year shows that there is a significant consistency between the estimated and actual power outputs. In the instantaneous temperature and solar radiation change values, there are small differences between the ACO algorithm and the actual values. The MAPE value was determined to be 16.433% per day. The error margin of the model in hourly estimates is higher than other time periods. This is due to the fact that sudden weather changes (cloudiness, temperature increase, etc.) during the day directly affect energy production. Energy insufficiency may occur especially in periods when there is little sunlight, such as early morning or late afternoon.

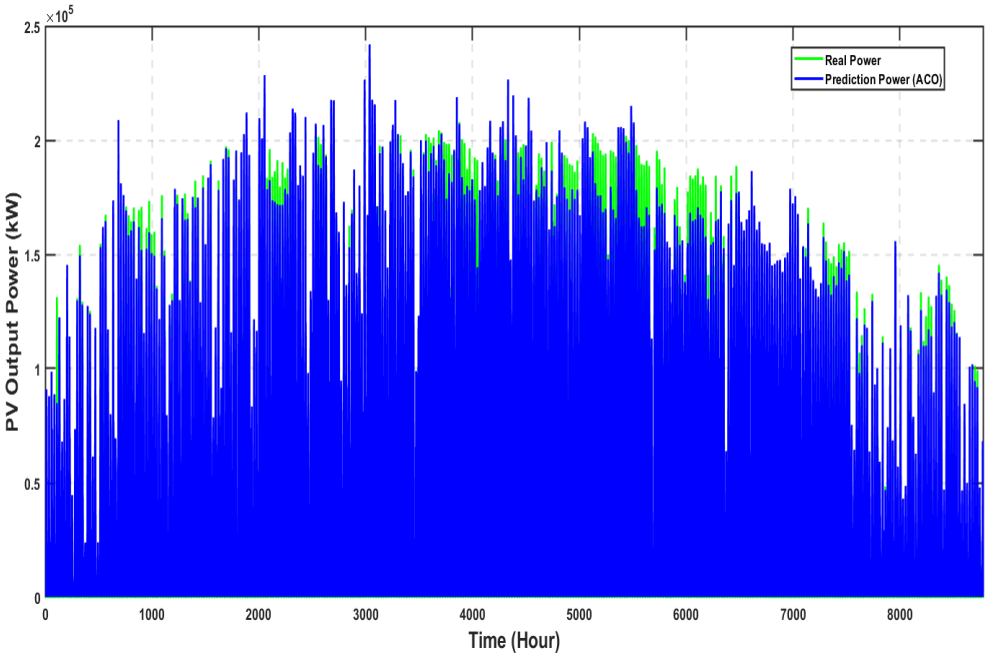

Figure 4. Graph of actual power and predicted output power in hours over a year

Figure 5 shows the correlation between daily actual power and estimated power over one year of data. The daily study shows that there is a significant consistency between the estimated and actual power outputs. However, the model was not able to adequately predict certain sudden short-term fluctuations. The MAPE value was determined to be 11.472% per day. Although daily forecast accuracy has been improved, short-term sudden changes can negatively affect model performance at this level. It is possible to benefit from this data in the daily scheduling of irrigation systems; for example, it can be said that the energy needs of water pumps can be met on days when sunlight is more intense, and battery support can be planned against energy shortage on cloudy days.

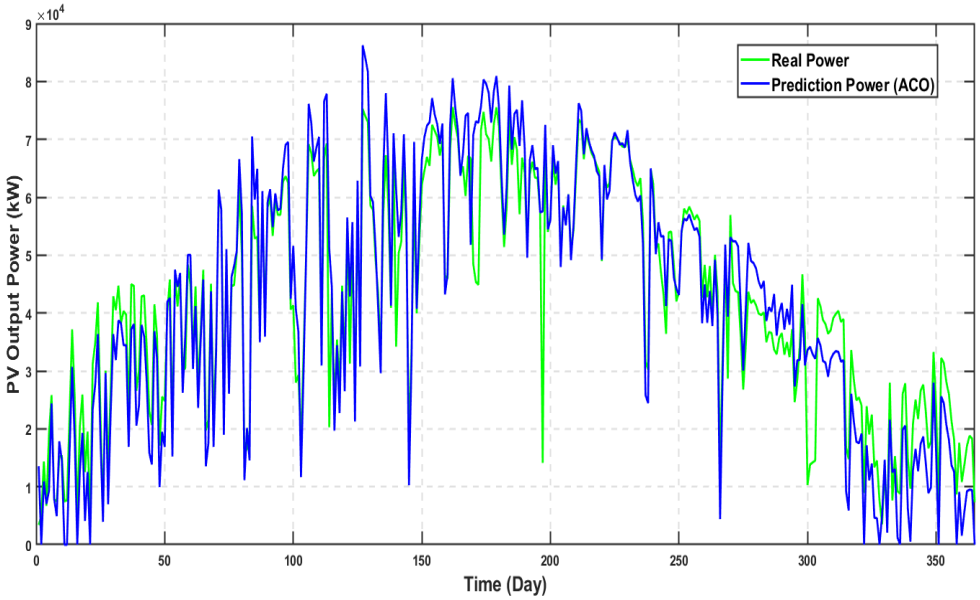

Figure 5. Graph of actual power and predicted output power by day of a year

Figure 6 shows the weekly changes in the real power value and the estimated power. The weekly analysis shows that the daily changes are more stable. The model has effectively determined the general trend and the error rate is reduced compared to the daily analysis. The MAPE value of the weekly estimates is determined as 9.705%. The weekly estimates provide a more stable view and show that the general trends in energy production are correctly captured. This level of accuracy can be very useful for farmers who create weekly irrigation schedules. For example, synchronizing the irrigation activities to be carried out on certain days of the week with energy production can increase the system efficiency.

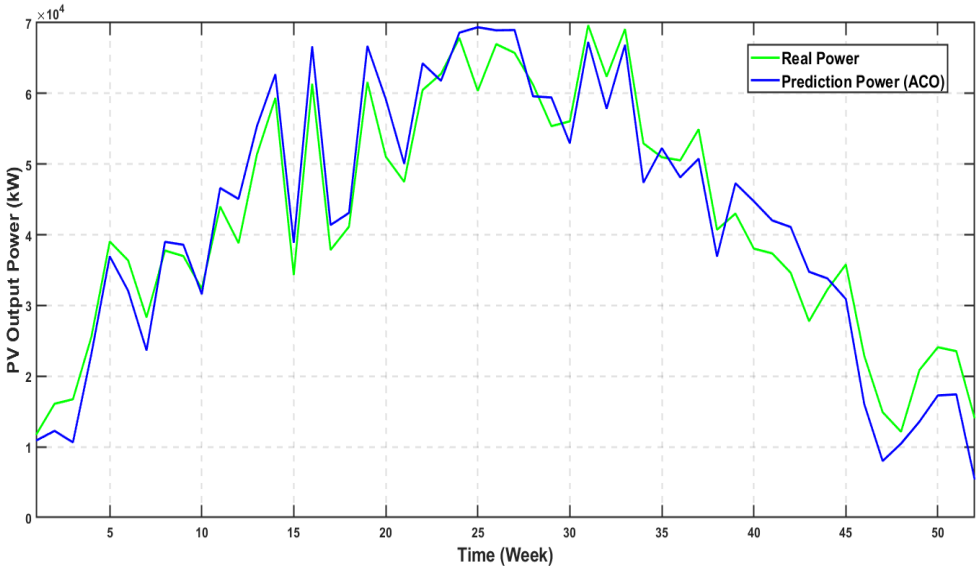

Figure 6. Graph of actual power vs predicted output power over weeks of a year

Figure 7 shows the actual and forecasted power values for twelve months. The monthly analysis shows that the model can predict power production with exceptional accuracy. Errors due to temporary fluctuations are less pronounced in this context, and the MAPE value is calculated as 7.414%. The lower margin of error in monthly forecasts allows the creation of long-term strategies in energy planning. Large-scale agricultural enterprises can more effectively manage irrigation frequency, system capacity and water consumption based on monthly energy production forecasts. In addition, energy storage solutions integrated into irrigation systems can be optimized with such forecasts.

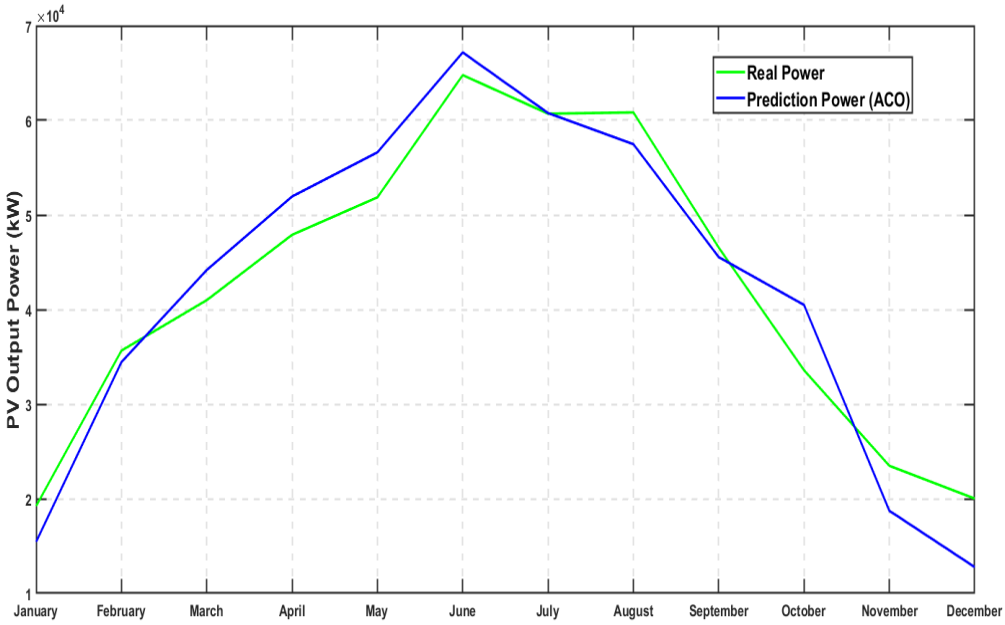

Figure 7. Twelve-month actual power vs. projected output power graph

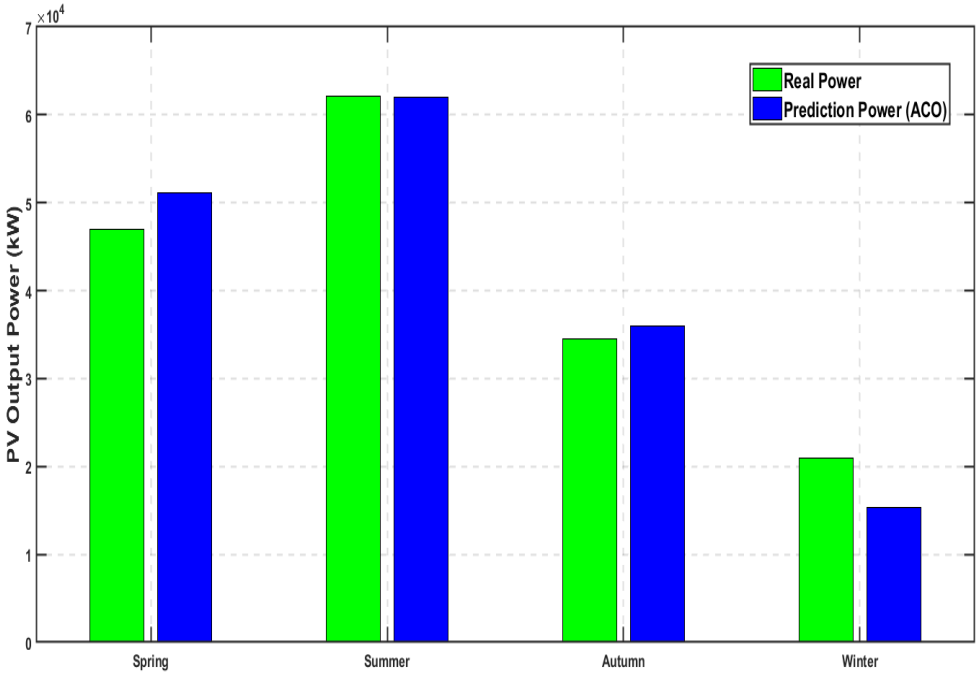

Figure 8. Graph of actual power and predicted power output for a one-year season

Figure 8 presents the graph of electricity production and forecast figures categorized by season. Seasonal analysis shows that the model captures long-term trends well. The power production output of the photovoltaic system reached its peak in the summer month when solar radiation is at its maximum intensity. Significant production differences between summer and winter seasons were evaluated. The MAPE value calculated on a seasonal basis is 5.045%. The observation of the lowest error rate in seasonal analyses shows that irrigation strategies can be structured on a seasonal basis. The increase in both energy production and water demand in summer months can be evaluated as the most efficient period for PV-supported irrigation systems. In this context, it is recommended that the installation of PV systems should be planned by taking into account the high performance especially in summer months.

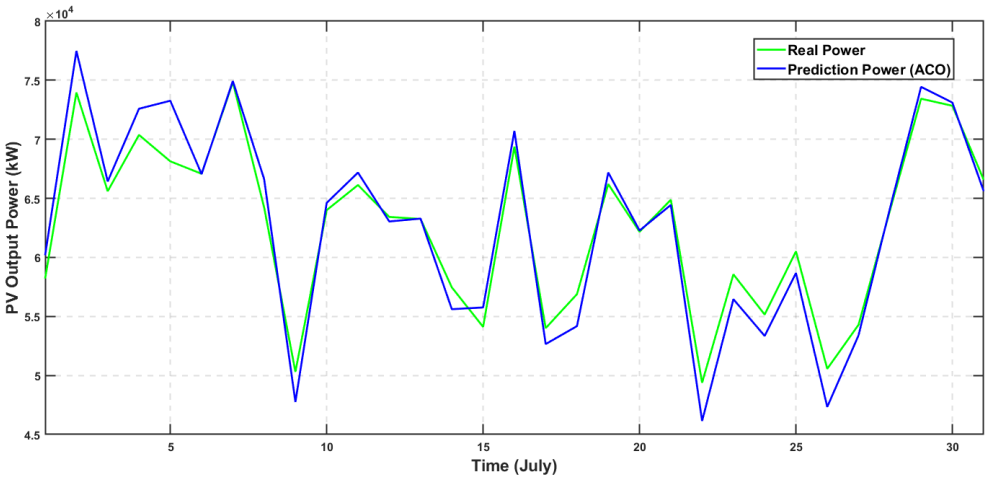

Figure 9. July actual power and projected output power chart.

Figure 9 shows the production and forecast graph for the July season, which is characterized by peak solar radiation. July was studied because it is the month with the highest solar radiation. The model predicted the power output for this month with exceptional accuracy. The MAPE value for July was determined as only 9.517%. July stands out as the period with the highest solar radiation. This is also the period when the irrigation demand is at its maximum. The high accuracy of the model during this period shows that the system can reliably meet the energy demand during the peak irrigation periods.

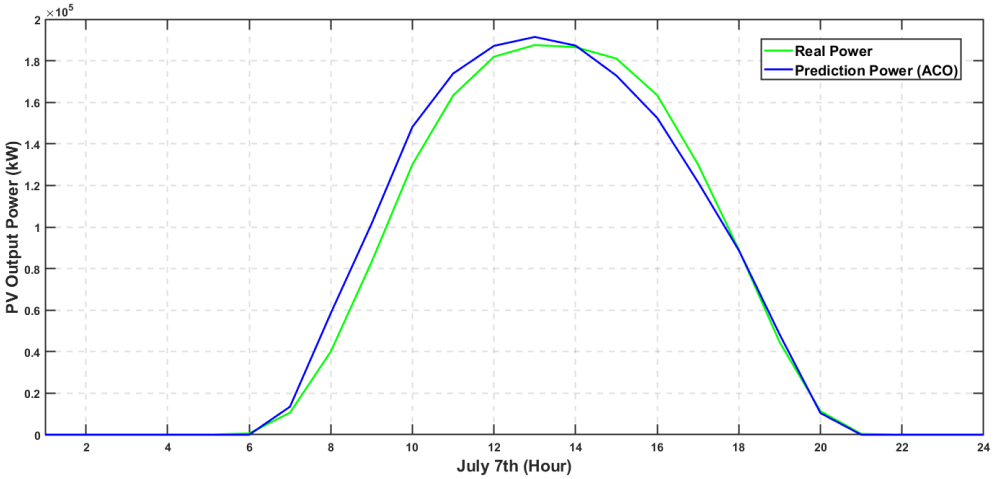

Figure 10. July 7, actual power and predicted output power chart.

Figure 10 presents the analytical results for the highest production day of the year, July 7th. The model for the highest production day is important for assessing short-term forecast accuracy. The expected power production on this particular day was remarkably consistent with the actual data. The analysis conducted for July 7th shows that the model can be used effectively in planning specific days.

Table 1. MAPE values according to different time intervals

Time Range	MAPE (%)
Hour	16.433
Day	11.472
Week	9.705
Month	7.414
July	9.517
July 7th	9.246
Season	5.045

Table 1 summarizes the MAPE values calculated for various periods. The accuracy rate of the model increases with the extension of the period. Although the error rate is high in daily forecasts, the model shows more efficiency in long-term forecasts. From the perspective of agricultural irrigation, weekly and monthly models have higher field applicability. Seasonal forecasts can play a leading role in strategic energy management and infrastructure planning.

CONCLUSION

The increasing dependence on renewable energy sources necessitates the development of accurate and efficient forecast models to optimize energy production and distribution. In this study, an ACO based approach was used to forecast the power output of PV systems by analyzing the relationships between solar radiation, temperature and historical energy production data. The results show that the ACO algorithm is quite effective in forecasting PV power output, especially for long-term forecasts. The ACO based model provided reliable forecasts and the MAPE values improved over long time intervals. While short-term (hourly and daily) forecasts showed slight deviations due to sudden weather fluctuations, weekly, monthly and seasonal forecasts showed significantly lower error rates. The lowest MAPE value (5.045%) was recorded for seasonal forecasts, demonstrating the algorithm's ability to capture long-term energy production patterns. The model is highly sensitive to environmental factors such as solar radiation and temperature changes. It was determined that increasing temperatures in summer reduce the PV panel efficiency, but energy production still reaches its peak thanks to the intensity of solar radiation. This shows that seasonal analysis is of great importance in planning energy-dependent agricultural applications such as irrigation. The comparison between the actual energy production and model predictions revealed a strong correlation confirming the reliability of the ACO-based prediction approach. Moreover, the scalability of the model allows its integration into large-scale solar farms, enhancing its utility for regional and national energy strategies. The algorithm effectively adapts to different time intervals, highlighting its potential for real-world applications in energy management and grid stability. The findings show that ACO is a robust and efficient technique to improve PV power output prediction. This approach can contribute to better energy planning, grid integration, and load management of solar energy systems. Overall, it is concluded that the model developed with the ACO algorithm provides a reliable, flexible, and effective prediction mechanism for PV systems, and can also be used as a decision support system in applications requiring energy management such as agricultural irrigation systems. Incorporating additional meteorological variables such as humidity and wind speed in future iterations could further refine the model's precision. Future research can explore hybrid optimization techniques and deep learning methods to further increase the prediction accuracy.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

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Original Article

Evaluating the Effects of Utilitarian and Hedonic Drivers on Milk Consumption: A Structural Equation Modeling Approach

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ABSTRACT

The study investigated the utilitarian and hedonic motives driving consumer milk consumption in the TRA1 region, and analyzed their direct and total impacts on their consumption satisfaction. Primary data were collected from 765 households in the TRA1 region. Structural interactive regression model was applied to examine the relationships among the factor dimensions validated by Confirmatory Factor Analysis. The structural models demonstrated acceptable fit based on established criteria. The results of the study indicated that the hedonic motives of reliability and brand image, influenced by consumer concerns regarding hygiene, reliability, and milk source, explained 33.4% of the variance in milk consumption satisfaction and had a 36.6% total effect. The utilitarian drivers of hygiene, milk source and content, and sensory quality, were influenced by concerns related to reliability, hygiene, milk source and content, and brand image. These utilitarian factors explained 72.7% of the variance in satisfaction and exhibited a 44.5% total effect within the SIRMs.

Key words: Brand image, Climate change, Concern attribute, Sensory motive, Structural interavtive regression model

Faydacı ve Hazcı Motiflerin Süt Tüketimi Üzerindeki Etkilerinin Değerlendirilmesi: Yapısal Eşitlik Modelleme Yaklaşımı

ÖZ

Bu çalışma, TRA1 bölgesinde süt tüketimini etkileyen faydacı ve hedonik motivasyonları incelemiş ve bunların tüketim memnuniyeti üzerindeki doğrudan ve toplam etkilerini analiz etmiştir. Birincil veriler, TRA1 bölgesindeki 765 haneden toplanmıştır. Doğrulayıcı Faktör Analizi ile geçerliliği kanıtlanmış faktör boyutları arasındaki ilişkileri incelemek için Yapısal Etkileşimli Regresyon Modeli kullanılmıştır. Yapısal modeller, belirlenmiş kriterlere göre kabul edilebilir düzeyde uyum göstermiştir. Çalışmanın sonuçları, tüketicilerin hijyen, güvenilirlik ve süt kaynağına ilişkin endişelerinden etkilenen güvenilirlik ve marka imajı gibi hedonik motivasyonların, süt tüketim memnuniyeti varyansının %33,4'ünü açıkladığını ve %36,6 toplam etkiye sahip olduğunu göstermiştir. Güvenilirlik, hijyen, süt kaynağı ve içeriği ve marka imajı ile ilgili endişelerden etkilenen hijyen, süt kaynağı ve içeriği ile duyusal kalite gibi faydacı faktörler, memnuniyet varyansın %72,7'sini açıklamış ve SIRMs dahilinde %44,5 toplam etki ortaya çıkarmıştır.

Anahtar kelimeler: Marka imajı, İklim değişikliği, Endişe niteliği, Duyusal motif, Yapısal interaktif regresyon model

INTRODUCTION

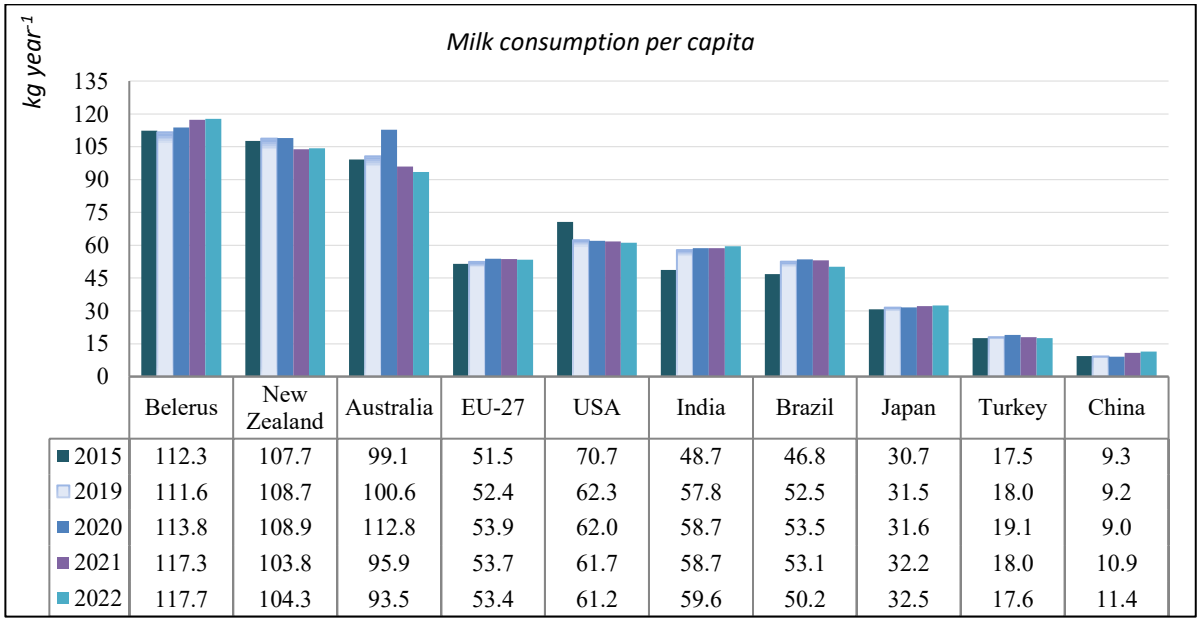
Food safety and security triggered by global climate change have adversely created on consumers' access to food products and their consumption patterns for the last decade (Li et al., 2022; Topcu and Elmi, 2023; Topcu, 2024; Parveen et al., 2025). The last researches showed that the animal-based food production and consumption were of much more negative impact on global climate change by increasing their ecological footprint that not

only resulted from land use change, feed production, manure emits, water and energy sources used in livestock farms and food industries, but also caused by carbon emission released in the animal products' consumption (Ritchie et al., 2018; Parveen et al., 2025). In other words, animal production (milk and milk product, meat and meat products) has considerably increased the ecological footprints, and then it has been constantly contributed to CO2 emission raise at their processing, marketing, retailing and consumption stages (Harguess et al., 2020; Topcu and Elmi, 2023; Topcu, 2024).

The relationship between milk production and consumption, and climate change has led to significant shifts in consumers dietary preferences over the last decade. Consumers have been increasingly favoring fruit and vegetable-based products over animal-based products (Ritchie et al., 2018; Li et al., 2022). This trend has been reflecting in dietary instructions in developed countries, which advocate for a shift from animal-based to plant-based diets as a strategy to mitigate environmental issues and combat climate change.

Dietary guidelines now emphasize the importance of mixed diets that prioritize plant-based foods while reducing animal-based products. This approach aims to minimize the negative impact on the environment. As a result, plant-based milk alternatives, such as soy, coconut, hemp, rice, pea, peanut, and oat milk, have been gaining popularity as substitutes for animal milk (Ritchie et al., 2018; Topcu, 2024). The past few years, therefore, have witnessed the emergence of sustainable consumption patterns, with a growing emphasis on mixed plant-based diets. In developed country (Australia, New Zealand, USA and EU-27), per capita consumption of animal-based milk has gradually declined since 2020. However, in developing and underdeveloped countries (China, India and Belarus) where traditional diets are prevalent, individual milk consumption has generally increased as mentioned in Figure 1 (Ritchie et al., 2018; TEPGE, 2023; CLAL, 2024).

Under intertwined impacts of climate change and the Covid-19 outbreak, milk consumption perception and purchasing patterns of developed and developing societies have completely differed from each other, and thus it has been exhibited reginal purchasing attitudes on milk consumption. It was also reported that the animal-based milk consumption was increasing in developing countries as compared to the developed countries, as well (Burnier et al., 2021; Topcu and Elmi, 2023; Topcu, 2024; Parveen et al., 2025). This increasing consumption of milk in developing countries is mainly correlated with rising urbanization, changing income and living styles, varying eating practices and consumer priorities triggered by utilitarian and hedonic motivation (Neima et al., 2021).



	Belerus	New Zealand	Australia	EU-27	USA	India	Brazil	Japan	Turkey	China
2015	112.3	107.7	99.1	51.5	70.7	48.7	46.8	30.7	17.5	9.3
2019	111.6	108.7	100.6	52.4	62.3	57.8	52.5	31.5	18.0	9.2
2020	113.8	108.9	112.8	53.9	62.0	58.7	53.5	31.6	19.1	9.0
2021	117.3	103.8	95.9	53.7	61.7	58.7	53.1	32.2	18.0	10.9
2022	117.7	104.3	93.5	53.4	61.2	59.6	50.2	32.5	17.6	11.4

Figure 1. Annual milk consumption per capita (kg year^{-1})

These concurrent crises have considerably reshaped consumers' attitude and purchasing patterns with the relative importance of traditional utilitarian and hedonic motivators. In other words, consumers' milk consumption satisfaction is more complex and multifaceted phenomenon driven by utilitarian needs (functional benefits: health, nutrition, practicality, content, knowledge, nutritional value, food quality and safety, convenience and durability, health concern, sensory appeal), hedonic desires (pleasure derived from consumption: taste, enjoyment, emotional connection, brand, label, information, prestige, comfort, affection, ambition, emotion, appeal, pleasure, familiarity, mood, hunger and thirst, reliability, and habits), and global

challenges (climate change and the Covid-19 epidemic: the sustainability of milk production, environmental impact, awareness of health and food safety and security) introducing new dimensions to consumer decision-making (Picot et al., 2021; Li et al., 2022; Shin et al., 2023; Topcu and Elmi, 2023; Putritamara et al., 2025).

The results of previous researches related to the consumption of milk products also highlighted that consumers' psychological factors (attitude and value, knowledge, skill, emotional and cognitive sensibility, taste and flavor) and ecological factors (natural sources and environment variables) impacting on their consumption perceptions and purchase attitudes were of a much more important than socioeconomic factors (culture and belief, social norm and status) and the external factors related to food marketing such as economic, political and legal factors by being the major drivers of utilitarian and hedonic motivation (Li et al., 2020; Ouyang et al., 2021; Topcu and Elmi, 2023).

According to FAO (2013) report, it was reported that major reason of increasing animal food demands in the early 2000s was created the motive impacts on communities' diet selection via various campaigns being applied individual utilitarian and hedonic motivation drivers (Gerber et al., 2013). Today, however, it has been focused on moderate mixed planted-based diets instead of animal-based diets through decision makers' various diet campaigns to be mitigated the negative impacts on climate change and ecological environment, and thus they have intensively tried to canalize consumers' utilitarian and hedonic motivational drives to this direction.

Analyzing the effects of sharp tactical changes in societies' consumption policies under the influence of climate change and epidemic diseases on consumers' utilitarian and hedonistic motivation is of great importance for future milk consumption planning and strategies. In this context, the aim of the study was to determine utilitarian and hedonic motives triggering on consumers' milk consumption in TRA1 region, and then to analyze their direct and total effects on their consumption satisfaction.

MATERIALS AND METHODS

Material

The research used data collected from households consuming milk in TRA1 Region (Erzurum, Erzincan and Bayburt). The data was gathered through a questionnaire approved by Ataturk University Ethics Committee with 2021/13 number. Secondary data was also used from registered data of several institutions and organizations, along with scientific books, journals, and research reports.

Method used in sample size calculation

The sample size was determined using the Simple Random Sampling Method, accounting the ratios of the main mass (Erzurum 75%), Erzincan 80%, and Bayburt 85%). The sample size for the TRA1 Region was calculated as 302 households for Erzurum, 258 for Erzincan, and 205 for Bayburt, totaling 765 households, as shown in Equation 1 (Churchill, 1995; Malhotra, 1996).

$$n = \frac{Z^2 \cdot p \cdot (p-1)}{c^2} \qquad (Eq.1)$$

Where,
n: sample size
Z: Z table value (1.96 for %95 confidence interval)
p: Milk consumption rates (Erzurum 75%, Erzincan 80%, and Bayburt 85%)
c: deviance from the mean (±0.05)

Method used in data collection

The scale, designed based on the results of Exploratory Factor Analysis (EFA) from researches conducted by Topcu (2019), Topcu (2019a), Topcu and Sarı (2019), Topcu and Sarı (2019a) and Topcu (2023) on milk purchasing attitudes, was structured as a questionnaire using a five-point Likert Scale (Table 1). This questionnaire was then used to collect the data from target consumer groups.

Table 1. Variables names and encodes related to milk consumption

Item codes	Item names	Item codes	Item names
M1	Taste and smell	M16	label information
M2	Flavor	M17	Promotion
M3	Color and fatness of milk	M18	Packaging
M4	Hygiene in animal feeding	M19	Manufacturer brand
M5	Hygiene at retail level	M20	Local brand
M6	Hygiene in milking	M21	Retailer brand
M7	Hygiene in milk processing	M22	Advertisement
M8	Trust to farmer	M23	Price-quality relation
M9	Trust to manufacturer	M24	Ecological footprint concern
M10	Trust to retailer	M25	Covid-19 concern
M11	Protein content	M26	Antibiotic residual and hormone concern
M12	Vitamin content	M27	Artificial milk concern
M13	Mineral matter content	M28	Sheep milk
M14	Calcium content	M29	Goat milk
M15	Fat ratio		

Methods used in statistical analyses

CFA model validity measurement

Convergent and discriminant validity of the CFA measurement model were evaluated for each factor dimension using standard metrics: Construct Reliability (CR), Average Variance Extracted (AVE), Maximum Shared Variance (MSV), and Average Shared Square Variance (ASV). To ensure construct validity within the CFA model, CR should be 0.70 (or higher), and AVE should exceed 0.50. Additinally, to establish discriminant validity, both MSV and ASV must be lower than AVE (Hair et al., 2014; Gürbüz, 2019; Civelek, 2020; Topcu, 2024). These measurements indicated adequate structural validity for each factor dimension in Table 2.

Table 2. MSV, ASV, AVE, CR measurement values and requirement conditions for each factor dimension.

Factor dimension	MSV		AVE		CR	AVE		ASV
Sensory	0.232	<	0.521	<	0.764	0.521	>	0.104
Hygiene	0.176	<	0.649	<	0.789	0.649	>	0.126
Reliability	0.117	<	0.591	<	0.741	0.591	>	0.082
Content	0.139	<	0.561	<	0.801	0.561	>	0.056
Brand image	0.129	<	0.492	<	0.823	0.492	>	0.093
Concern	0.118	<	0.561	<	0.833	0.561	>	0.070
Milk source	0.103	<	0.719	<	0.835	0.719	>	0.030

CFA model goodness of fit tests

The *CMIN/df* ratio was used to assess the overall goodness of fit for the structural interactive regression models *(SIRMs)*. Ratios below 3 and 5 were deemed acceptable for overall goodness and acceptable fit, respectively. Multiple indices were considered, including the *IFI, CFI,* and *RMSEA*. The IFI was chosen due to its ability to handle a wide range of problem solution, variation in problem solutions, while the *CFI* and *RMSEA* were considered due to their sensitivity to sample sizes in comparative fit indices. For *IFI* and *CFI* values greater than 0.90 and 0.95, respectively, indicate good and acceptable fit. For *RMSEA*, value below 0.08 and 0.10 indicate good and acceptable fit, respectively (Browne and Cudeck, 1993; Hu and Bentler, 1999; Gürbüz, 2019).

The *GFI* measures the degree to which the *SIRMs*' predicted relationships align with the actual relationships in the data. A *GFI* of 0.90 or higher is considered acceptable. The *RMR/SRMR* evaluates the average difference between the observed and model-implied covariance matrices. An *RMR/SRMR* of 0.08 or lower is often considered acceptable (Marsh et al., 1988; Meydan and Şeşen, 2015; Civelek, 2020).

The factors that demonstrated convergent and discriminant validity and influence consumer milk consumption were included in the *SIRMs*. This model elucidates the linear relationships between unobserved (latent) factors, which are constructed from measurable variables. These variables can be either exogenous/independent or endogenous/dependent (Figure 2). SIRM refers to modelling complex relationships among multiple latent (unobserved) and observed variables. Moreover, it implies the inclusion of interaction terms to model how the impact of one variable depends on another.

The *SIRMs*, therefore, combines the *CFA* and path analysis, similar to multiple regression, and determines the extent to which correlations among exogenous and endogenous factors are consistent with those predicted

in path model. It also assesses the total effects (direct and indirect effects) of the exogenous factors on the endogenous factors (Nunkoo and Ramkissoon, 2011; Meydan and Şeşen, 2015; Civelek, 2020). IBM AMOS 24.0 was used for the *CFA* and the *SIRMs*.

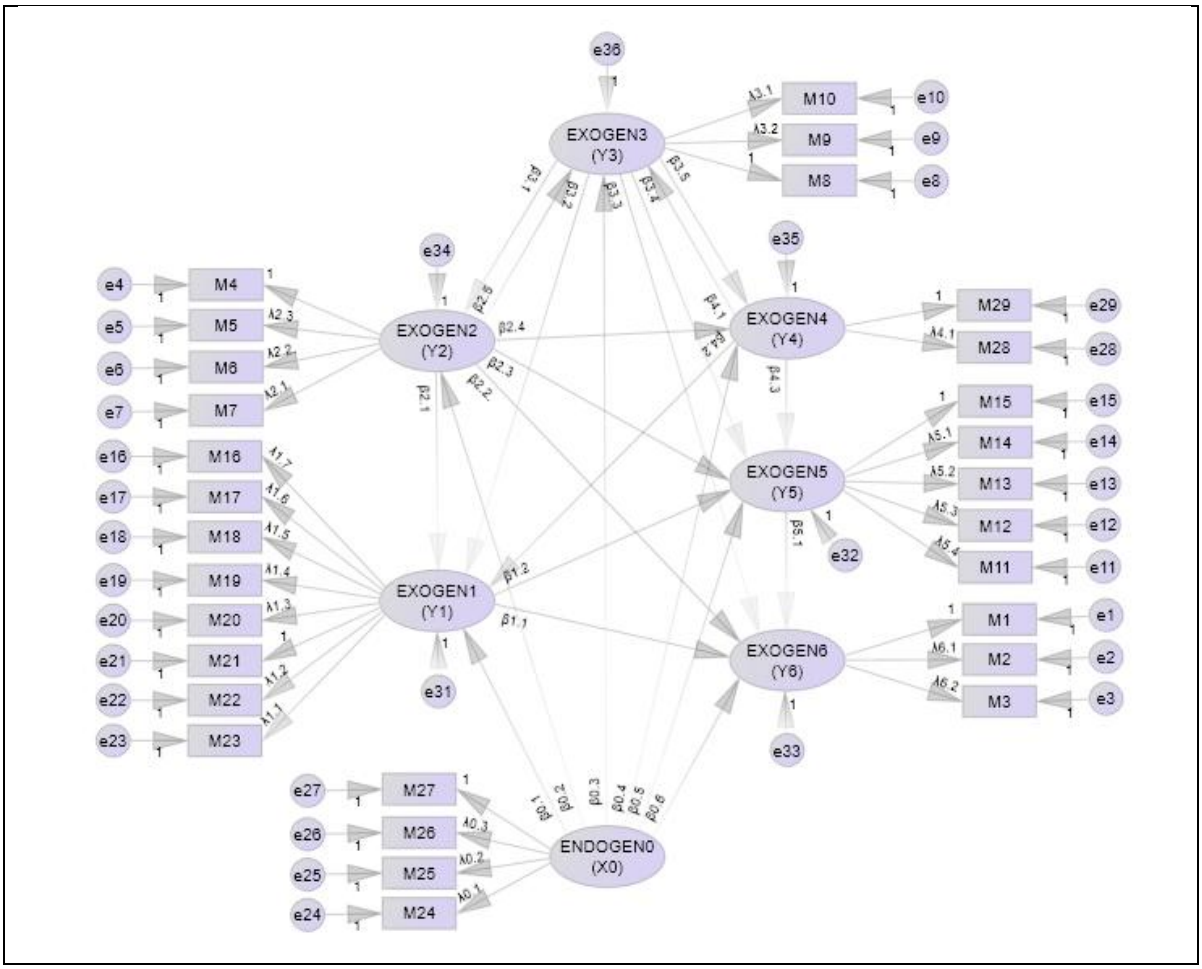


Figure 2. Specification and path diagram of structural interactive regression model *(SIRM)*

The mathematical notation and specifications of the *SIRMs* in Figure 2 were given in the following Equations.

$$Y_3 = \beta_{0.3}X_0 + \beta_{2.5}Y_2 + \beta_{4.1}Y_4 \quad \textit{(Eq. 2)}$$

$$Y_2 = \beta_{0.2}X_0 + \beta_{3.2}Y_3 \quad \textit{(Eq. 3)}$$

$$Y_1 = \beta_{0.1}X_0 + \beta_{2.1}Y_2 + \beta_{3.2}Y_3 + \beta_{4.2}Y_4 \quad \textit{(Eq. 4)}$$

$$Y_4 = \beta_{0.4}X_0 + \beta_{2.4}Y_2 + \beta_{3.5}Y_3 \quad \textit{(Eq. 5)}$$

$$Y_5 = \beta_{0.5}X_0 + \beta_{1.2}Y_1 + \beta_{2.3}Y_2 + \beta_{3.4}Y_3 + \beta_{4.3}Y_4 \quad \textit{(Eq. 6)}$$

$$Y_6 = \beta_{0.6}X_0 + \beta_{1.1}Y_1 + \beta_{2.2}Y_2 + \beta_{3.3}Y_3 + \beta_{5.1}Y_5 \quad \textit{(Eq. 7)}$$

RESULTS AND DISCUSSION

The *SIRMs* diagram and their some statistical results based on the SIRMs related milk consumption satisfaction of consumers were presented in Figure 3. The results of the SIRMs indicated that the factor dimensions, including in sensory quality, hygiene, reliability, content/product information, brand image, concern, and milk supply source demonstrated a fairly good level in terms of overall, absolute, and comparative goodness-of-fit indices. It was analyzed that the *CMIN/df*, *RMSEA*, and *SRMR* values indicated an excellent fit, while the *IFI* and *CFI, GFI and RMR* values indicated an excellent fit. In conclusion, overall goodness-of-fit indices of the *SIRMs* showed that it had a noticeably good fit with the used data and fell within the range of suitable criteria (Table 3).

Table 3. Overall, absolute and comparative fit indices and threshold ranges of the *CFA* model

Fit indices	*Goodness of fit indices*	*Acceptable fit indices*	*CFA measurement model*
CMIN/DF	<3.00	<5.00	2.816
IFI	>0.95	>0.90	0.923
CFI	>0.95	>0.90	0.923
GFI	>0.95	>0.80	0.917
RMSEA	<0.08	<0.10	0.049
RMR	<0.05	<0.08	0.056
SRMR	<0.05	<0.08	0.050

The results of the measurement and the *SIRMs* analyzing consumers' milk consumption satisfaction were presented in Table 3 and 4. The results highlighted that item scores created under sensory quality varied from β_0*=0.66 (p<.001)* to β_0*=0.81 (p<.001),* and taste and smell *(M1)* was the most effective *(β_0=0.81)* and explanatory *(R^2=0.66)* variable (Table 4 and Figure 3).

Variable loadings based to hygiene and reliability on milk consumption satisfaction were found the range from β_0*=0.57* and *0.60 (p<.001)* to β_0*=0.76* and *0.83 (p<.001),* and hygiene in animal feeding at farm level *(M4)* and trust in the manufacturer *(M9)* were evaluated as the strongest *(β_0=0.76 and 0.82)* and explanatory *(R^2=0.58 and 0.68)* items. Similarly, item scores of product content/information varied from β_0*=0.47 (p<.001) to* β_0*=0.84 (p<.001)*, and protein *(M11)* and vitamin *(M12)* were the most effective *(β_0=0.84 and 0.80)* and explanatory *(R^2=0.70 and 0.64)* variables (Table 4 and Figure 3).

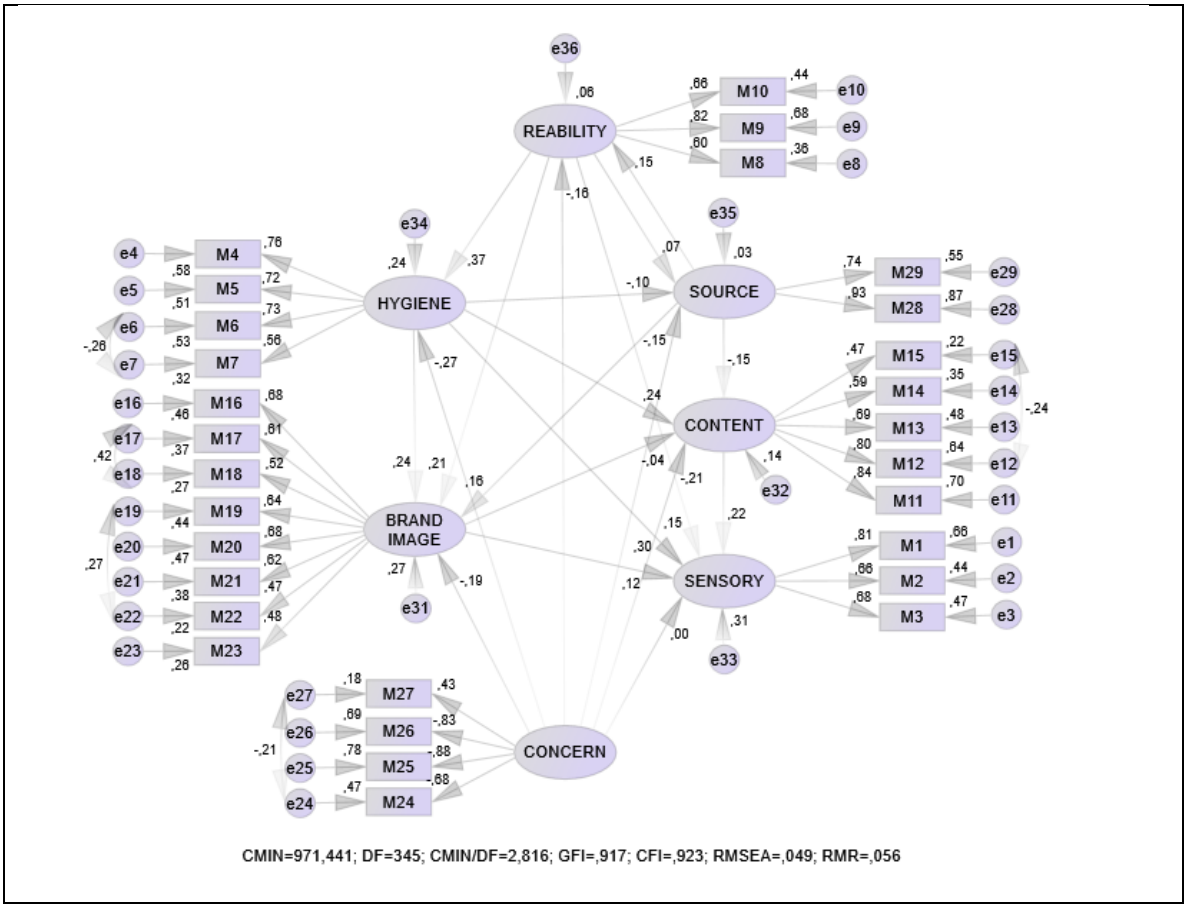


Figure 3. The results and fit statistics of improved structural regression model

The results of the *SIRMs* also shown that variable coefficients of brand image on milk consumption satisfaction changed between β_0*=0.47 (p<.001)* and β_0*= 0.69 (p<.001)*, and that local brand *(M20)*, label information *(M16)* and manufacturer brand *(M19)* were the most impact *(β_0=0.69, 0.68 and 0.64)* and explanatory *(R^2=0.47, 0.46 and 0.44)* items (Table 4 and Figure 3). It was pointed out that the factor of *concern* impacting adversely milk consumption satisfaction varied from β_0*=0.42 (p<.001)* to β_0*=-0.88 (p<.001)*, and that *Covid-19 infection (M25)* and *antibiotic residual and hormone anxieties (M26)* were the most impact *(β_0=-0.88 and -0.83)* and explanatory *($R^2 = 0.78$ and 0.69)* items. In addition, the results of the *SIRMs* indicated that

variable coefficients and relative explanation levels of *sheep milk (M28)* and *goat milk supply sources (M29)* were β_0*=0.93 and 0.75 (p<.001),* and R^2*=0.87 and 0.55* respectively (Table 4 and Figure 3).

Table 4. The measurement model results related to consumers' milk consumption

Items	Path	Factors	β_0	β_1	*S.E.*	*C.R.*	*p*
M1	<---	Sensory	0.812	1.000			
M2	<---	Sensory	0.678	0.989	0.064	15.560	***
M3	<---	Sensory	0.682	0.869	0.055	15.864	***
M4	<---	Hygiene	0.760	1.000			
M5	<---	Hygiene	0.567	0.833	0.063	13.186	***
M6	<---	Hygiene	0.727	0.921	0.053	17.377	***
M7	<---	Hygiene	0.718	0.915	0.050	18.220	***
M8	<---	Reliability	0.601	1.000			
M9	<---	Reliability	0.826	1.437	0.106	13.533	***
M10	<---	Reliability	0.659	1.273	0.096	13.288	***
M15	<---	Content	0.473	1.000			***
M11	<---	Content	0.836	1.417	0.115	12.307	***
M12	<---	Content	0.798	1.370	0.119	11.507	***
M13	<---	Content	0.692	1.308	0.113	11.625	***
M14	<---	Content	0.589	0.992	0.092	10.799	***
M21	<---	Brand image	0.620	1.000			
M16	<---	Brand image	0.682	1.232	0.086	14.270	***
M17	<---	Brand image	0.472	0.899	0.079	11.424	***
M18	<---	Brand image	0.525	0.929	0.079	11.754	***
M19	<---	Brand image	0.644	1.166	0.081	14.327	***
M20	<---	Brand image	0.685	1.283	0.094	13.610	***
M22	<---	Brand image	0.543	1.319	0.110	11.969	***
M23	<---	Brand image	0.482	0.897	0.084	10.732	***
M27	<---	Concern	0.424	1.000			
M26	<---	Concern	-0.830	-2.108	0.184	-11.439	***
M25	<---	Concern	-0.884	-2.300	0.200	-11.477	***
M24	<---	Concern	-0.682	-1.644	0.138	-11.889	***
M29	<---	Source	0.747	1.000			
M28	<---	Source	0.926	1.248	0.110	11.326	***

β_0: Standardized path coefficients *β_1:Unstandardized path coefficients* *$^{***}p < .001$*

Six *SIRMs*, as defined by Equation 2-7, were analyzed to determine the influence of consumer concern (endogenous variable) and other endogenous factors on exogenous variables, considering both total and indirect effects (Table 4 and Figure 3). The results of the research indicated a negative correlation between the concern factor (comprising ecological footprint, Covid-19 contamination, artificial milk production, and chemical residues) and key exogenous variables influencing consumer milk consumption, namely reliability, hygiene, brand image, milk supply sources, and milk content. The total and direct effects of the concern factor ranged from *-0.180 (p<.001)* and *-0.004 (p=.924)* to *-0.339 (p<.001)* and *-0.272 (p<.001)*, respectively.

Numerous studies were shown that concerns regarding the ecological impact of milk and milk products, the Covid-19 pandemic, antibiotic residues and hormones, and artificial milk production claims have negatively affected consumer satisfaction with milk consumption. Additionally, the Covid-19 pandemic and climate change were adversely affected consumer purchasing attitudes in agri-food markets, from dairy farms to food retailers, owing to concerns about food quality and safety, its components, hygiene, and trust in dairy market actors. These concerns about food quality and safety have led to a significant decrease in consumer milk demand across all economic and social systems (Macready et al., 2020; Shamim et al., 2021; Skalkos et al., 2021). In particular, the Covid-19 pandemic, along with growing awareness of the ecological and water footprint of dairy farming and its industrial applications, has contributed to climate change, leading to increasingly negative trends in milk consumption attitudes and behaviors of consumers.

When each *SIRMs* was taken into consideration, the results of the model in Equation 2 indicated that consumers' trust in dairy supply chain actors (reliability factor) as a hedonic driver on their consumption satisfaction was negatively affected by the concern factor with 16% direct and 18% total effect rates *(β_0=-0.160*

and δ_0=*-0.180 (p<.001))*, but it was not found to have significant direct and total effects of the milk supply source factor on the reliability factor in view of economical and statistical theories (Table 5 and Figure 3). Hence, there were negative effects of the concern and milk supply source factors on the reliability factor, and these factors explained only 6.4% of the variation in the reliability factor.

The recent studies (Topcu and Sarı, 2019; Cruz et al., 2021; Skalkos et al., 2021) highlighted the critical role of consumer trust in dairy market actors, particularly concerning food purchase intention and consumption satisfaction during Covid-19 pandemic. These studies indicated that trust in the dynamics of the short food supply chain was a significant predictor of food acceptance, as it mitigates perceived risks, especially regarding potential negative environmental impacts from chemical pollutants. Furthermore, these studies suggested that trust influences consumer purchasing decisions, with greater trust in the dairy product supply chain associated with higher purchase intention and consumption satisfaction. The current research supported these findings, demonstrating that reliability (trust in dairy market actors) was a key factor in consumer milk consumption satisfaction, while hedonic motives were of a comparatively lower impact.

The results of the study showed that hygiene under a utilitarian motive in the processes extending from dairy farms to retailer shelves had a meaningful functional relationship with the concern and reliability factors, which assessed by 24% explanation rate *(R^2= 0.241)* on consumers' milk consumption satisfaction (Equation 3 and Table 5). In these interactions, the direct and total effects of the concern and reliability factors on the hygiene factor were analyzed to be β_0=*-0.272* and δ_0=*-0.339 (p<.001)* and β_0=*0.373* and δ_0=*0.339 (p<.001)*, respectively. The hygiene factor attributing a positive correlation with the reliability factor compared to a negative relationship with the concern factor on consumption satisfaction was, therefore, represented by moderate interactive factors.

Table 5. SIRM model results based on consumers' milk consumption satisfaction

Factors	Path	Factors	δ_0	β_0	β_1	S.E.	C.R.	p
Reliability	<---	Concern	*-0.180*	*-0.160*	-0.209	0.067	-3.143	***
	<---	Source	*0.153*	*0.152*	0.087	0.099	0.883	.377
R^2= 0.064								
Hygiene	<---	Concern	*-0.339*	*-0.272*	-0.431	0.074	-5.818	***
	<---	Reliability	*0.375*	*0.373*	0.453	0.060	7.489	***
R^2= 0.241								
Brand image	<---	Concern	*-0.332*	*-0.193*	-0.323	0.078	-4.141	***
	<---	Hygiene	*0.219*	*0.240*	0.253	0.054	4.680	***
	<---	Reliability	*0.302*	*0.206*	0.264	0.066	4.014	***
	<---	Source	*0.204*	*0.158*	0.116	0.031	3.693	***
R^2= 0.270								
Source	<---	Concern	*-0.129*	*-0.150*	-0,343	0.126	-2.726	***
	<---	Hygiene	*-0.098*	*-0.098*	-0.141	0.077	-1.839	*
	<---	Reliability	*0.029*	*0.066*	0.115	0.305	0.379	.705
R^2= 0.033								
Content	<---	Concern	*-0.259*	*-0.210*	-0.215	0.051	-4.239	***
	<---	Hygiene	*0.246*	*0.240*	0.156	0.033	4.670	***
	<---	Source	*-0.147*	*-0.152*	-0.069	0.019	-3.554	***
	<---	Brand image	*-0.038*	*-0.038*	-0.023	0.031	-0.755	.450
R^2= 0.140								
Sensory	<---	Concern	*-0.233*	*-0.004*	-0.006	0.066	-0.095	.924
	<---	Reliability	*0.321*	*0.154*	0.175	0.057	3.088	***
	<---	Hygiene	*0.380*	*0.302*	0.284	0.050	5.694	***
	<---	Brand image	*0.114*	*0.122*	0.108	0.044	2.438	**
	<---	Content	*0.222*	*0.222*	0.321	0.066	4.855	***
R^2= 0.313								

β_0: Standardized path coefficients (direct effects) *β_1: Unstandardized path coefficients*

δ_0: Total effect (direct effect (β_0)+indirect effect) *$^{***}p < .001$* *$^{**}p < .05$* *$^{*}p < .10$*

Additionally, the study revealed a strong relationship between hygiene (in processes from dairy farms to retail shelves) and both consumer concern and reliability (Equation 3 and Table 5), explaining 24% of the variance in consumer milk consumption satisfaction *(R^2=0.241).* In these interactions, the direct and total effects of concern and reliability on hygiene factor were analyzed, revealing significant associations *($в_0$=-0.272* and *$δ_0$=-0.339 (p<.001)* and *$в_0$=0.373* and *$δ_0$=0.339 (p<.001), respectively)*. Notably, hygiene exhibited a positive correlation with reliability and a negative relationship with concern, suggesting that it was influenced by a combination of interactive factors.

The research highlighted a strong correlation between hygiene and reliability factors in consumer satisfaction with milk consumption. It all starts with clean milk production, which relies on health animals and sanitary condition on dairy farms. To prevent contamination, rigorous hygiene must be maintained at every steps; animal care covering proper housing, management, veterinary care, and diseases prevention, milking and processing including in strict sanitary practices during milking, processing, and packaging, distribution and retail consist of safe handing, and storage to maintain quality (Paraffin et al., 2017; Alegbeleye et al., 2018; Willis et al., 2018; Topcu and Elmi, 2023; Topcu, 2024). Thanks to advancements in waste management, distribution, hygienic practices, the dairy industry has significantly reduced contamination risks. Milk processed under these conditions is safe for everyone. Consequently, consumer satisfaction has significantly increased in recent years, driven by innovations in animal care, manufacturing, and retail.

The results of the *SIRMs* in Equation 4 suggested that the direct and total effects of concern, hygiene, reliability, and milk supply source factors on the brand image, satisfying consumer milk consumption, were tested as *$в_0$=-0.193* and *$δ_0$=-0.332 (p<.001), $в_0$=0.240* and *$δ_0$=0.219 (p<.001), $в_0$=0.206* and *$δ_0$=0.302 (p<.001),* and *$в_0$=0.158* and *$δ_0$=0.204 (p<.001),* respectively, and their explanatory rate on the brand image as a hedonic motive was 27% *(R^2=0.270).* There was a negative correlation between brand image and concern factor, but positive relationships among the brand image and the others (Table 5).

The last studies on brand image highlighted its pivotal role in influencing consumer products selection and repurchase attitude, thereby establishing it as a key metric for satisfaction and a driver of competitive advantage (Perito et al., 2019; Rihn et al., 2019; Slade et al., 2019; Marchini et al., 2021). The findings of the study also indicated that brand image, encompassing labeling information related to milk content and quality, along with health claims pertaining to sanitary production and trust in market actors, constituted a crucial determinant for consumers. Consequently, it is plausible that brand image, through favorable motivational drivers related to consumption satisfaction and purchase perception, could substantially augment sustainable consumption patterns. Cumulatively, the results underscored that brand image, as a hedonic motive, significantly influenced consumer satisfaction and attitudes, purchase decision, and willingness to pay for dairy products, demonstrating a positive correlation with their consumption satisfaction levels.

In Equation 5 and Table 5, the results of the *SIRMs* revealed that while concern and hygiene factors had statistically significant negative effects *($в_0$=-0.150* and *$δ_0$=-0.129 (p<.001), $в_0$=-0.098* and *$δ_0$=-0.098 (p<.10))* on milk supply sources under a utilitarian motive, the reliability factor did not exhibit meaningful impacts *($в_0$= 0.066* and *$δ_0$= 0.029 (p=0.705)).* Notably, it was observed that sheep and goat milk, compared with cow milk, were not commonly preferred by consumers in the research region for milk consumption satisfaction. Consequently, the explanatory impact of other factors on sheep and goat milk sources was calculated to be 3.3% *(R^2=0.033).*

The studies investigating the effects of milk from various species, such as cows, sheep, and goats, on human dietary intake were reported that sheep and goat milk contain higher levels of key macro-nutritional components, essential and trace minerals, protein, vitamins, lipids, and total solids compared to cow's milk. These types of milk, which are not subjected to intensive sanitary applications and chemical and microbiological contamination, could be used as alternatives for those with cow's milk allergies. Consuming sheep and goat milk, therefore, were shown to provide greater benefits to bone health than consuming cow's milk (Burrow et al., 2018; Moatsou and Sakkas, 2019). Contrary to previous studies, it is nearly impossible to find sheep and goat milk in local markets within the research region, and thus, this scarcity might attribute to the prevalence of dairy cow farming under the specific geographical and agro-ecological conditions, as well as consumers' socio-cultural attitudes, economic circumstances, and consumption preferences. It was determined that goat and sheep milk, compared to cow milk, had a much lower impact on consumer satisfaction with milk consumption, even when considering chemical and Covid-19 pandemic contamination. Hence, the impacts of sheep and goat milk sources on milk consumption satisfaction were not found to be positive.

The study's results also indicated that milk content, as a utilitarian motive, was significantly influenced by concerns about hygiene and the milk source *($в_0$=-0.210* and *$δ_0$=-0.259 (p<.001), $в_0$=0.240* and *$δ_0$=0.246 (p<.10)* and *$в_0$=-0.152* and *$δ_0$=-0.147 (p<.001),* respectively). However, brand image did not have a significant impact *($в_0$=-0.038* and *$δ_0$=-0.038 (p=.450)* in Equation 6 and Table 5. Overall, milk content was explained by a 14% variation rate *(R^2=0.140)* due to other factors.

Experimental research shown that dairy products, widely and frequently consumed in human diets, were a vital source of protein, vitamins, and minerals. Their consumption strengthens the musculoskeletal system, preventing osteoporosis, and could reduce the risk of coronary heart disease, stroke, dental caries, hypertension, and various types of cancer. The studies also indicated that fostering positive consumer attitudes, rather than negative beliefs about milk content, through reliable supply sources and sanitary manufacturing practices, leads to increased positive perceptions and demand (Um et al., 2019; Guo et al., 2020; Perez et al., 2020).

The results of this study, highlighted in Equation 7 and Table 5, demonstrated that sensory quality, as a utilitarian motive, had a significant positive linear correlation with reliability, hygiene, brand image, and milk content factors *(β_0= 0.154* and *δ_0= 0.321 (p<.001), β_0= 0.302* and *δ_0= 0.380 (p<.001), (β_0= 0.114* and *δ_0= 0.122 (p<.05)* and *β_0= 0.222* and *δ_0= 0.222 (p<.001),* respectively), but not with the concern factor *(β_0=-0.004* and *δ_0=-0.233 (p=.924)* in view of statistical and economic theories. These factors explain sensory quality as a strong moderate factor with a 31.3% explanatory rate *(R^2=0.313)*. As there was no widespread effect of sheep and goat's milk consumption on cow's milk consumption, the milk supply source factor did not have a significant effect on the model in Equation 7 and thus was removed from the model.

Prior research on the sensory attributes of milk has established that organoleptic properties (taste, odor, color, flavor) and fat content were major determinants of consumer satisfaction, with a strong positive correlation between purchase intentions and high sensory quality (Topcu, 2015; Rana and Paul, 2017). They found that sensory quality, encompassing milk composition, safety, and hygiene, exerted a strong influence on consumer purchase intentions and attitudes in the USA and Europe, particularly within established brand images. Similarly, Ouyang et al. (2021) emphasized the importance of sensory appeal in dairy products for brand loyalty, highlighting the role of trust in dairy market stakeholders regarding sanitary practices and the direct impact on consumer preferences.

CONCLUSION

To investigate the effects of utilitarian and hedonic motivations on milk consumption satisfaction in the TRA1 Region, under conditions of climate change and the Covid-19 pandemic, data from 765 households were analyzed using the CFA, and the SIRMs. The findings of the study revealed a measurement model consisting of seven factors influencing consumer milk consumption satisfaction: sensory quality, safety, hygiene, health concern, brand image, milk source, and milk composition. The model demonstrated good fit based on overall (CMIN/df), comparative (CFI, IFI, RMSEA, SRMR), and absolute (GFI, RMR) fit indices.

The results of the study also indicated that the concern factor in six SIRMs, which associated with seven factors on consumers' milk consumption satisfaction, negatively affected the other factors, and especially the hygiene, brand image factors in view of total effect. Consumers' trust to the actors at dairy markets (reliability) and brand image factors as the hedonic motives under the effects of the concern, hygiene, reliability and milk supply source factors were of 33.4% explanatory rate and 36.6% total effect on their milk consumption satisfaction. On the other hand, the hygiene, supply milk source and content, sensory quality factors as the utilitarian drivers were affected by the concern, reliability, hygiene, milk supply source and content, brand image factors, and thus their explanatory rate were calculated as 72.7% and 44.5% total effect on those in interactive structural regression models. It was analyzed that, therefore, the utilitarian motives compared with the hedonic drivers satisfying on consumers' milk consumption under climate change and Covid-19 pandemic conditions were much more effective and explanatory.

Consequently, in order to mitigate ecological footprint and the ethical and environmental concerns in milk consumption, it should be encouraged and supported sheep and goat milk farming along with plant-based milk instead of dairy cow farming in milk production. Therefore, it should be focused on the utilitarian motives of dairy products including in sensory quality under sanitary processes and consumer' trust to the market actors at dairy products supply chain as well as milk content with plant-based milk and with milk obtained from sheep and goat species, and then it should be diversified milk under brand images from hedonic motives influencing on target consumers' milk consumption satisfaction.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

***Yavuz TOPCU*:** Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; writing-original draft; writing-review and editing.

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Original Article

Comparative Performance Analysis of Deep Learning Based CNN Models for Diagnosis of Corn Leaf Diseases

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ABSTRACT

This study comparatively analyses the effectiveness of deep learning based on the convolutional neural network (CNN) models in the diagnosis of corn leaf diseases. Accurate and rapid diagnosis of leaf diseases, which cause serious economic losses in agricultural production, is critical for production efficiency. In this context, different CNN architectures (AlexNet, GoogLeNet, ResNet, DenseNet, EfficientNet, MobileNet and ConvNeXt) were used to perform classification on Corn leaf images. Model performances were evaluated with metrics such as accuracy, F1 score, precision and ROC-AUC. The results showed that modern architectures (especially ConvNeXtNet) provide higher performance. These findings support the practical applicability of artificial intelligence-supported automatic diagnosis systems in agriculture.

Key words: Deep learning, Corn leaf diseases, CNN, Image classification, ROC-AUC, Precision

Mısır Yaprak Hastalıklarının Teşhisinde Derin Öğrenme Tabanlı CNN Modellerinin Karşılaştırılmalı Performans Analizi

ÖZ

Bu çalışma, mısır yaprak hastalıklarının teşhisinde derin öğrenme temelli evrişimsel sinir ağı (CNN) modellerinin etkinliğini karşılaştırmalı olarak analiz etmektedir. Tarımsal üretimde ciddi ekonomik kayıplara neden olan yaprak hastalıklarının doğru ve hızlı teşhisi, üretim verimliliği açısından kritik öneme sahiptir. Bu bağlamda, farklı CNN mimarileri (AlexNet, GoogLeNet, ResNet, DenseNet, EfficientNet, MobileNet ve ConvNeXt) kullanılarak mısır yaprağı görüntüleri üzerinde sınıflandırma işlemi gerçekleştirilmiştir. Model performansları doğruluk, F1 skoru, keskinlik ve ROC-AUC gibi metriklerle değerlendirilmiştir. Sonuçlar, modern mimarilerin (özellikle ConvNeXtNet) daha yüksek başarı sağladığını göstermiştir. Bu bulgular, tarımda yapay zekâ destekli otomatik tanı sistemlerinin pratikte uygulanabilirliğini desteklemektedir.

Anahtar kelimeler: Derin öğrenme, Mısır yaprak hastalıkları, CNN, Görüntü sınıflandırma, ROC-AUC, Keskinlik

INTRODUCTION

The agricultural sector is of critical importance in terms of ensuring food security on a global scale, as well as contributing to economic development. The efficiency of agricultural production is of great importance in terms of meeting global food needs and ensuring sustainable production. As posited by Lenk et al. (2007), agriculture fulfils a dual function in human society. In addition to providing sustenance, it also serves to supply raw materials that are indispensable to economic growth, employment, and industry. However, the agricultural sector is confronted with numerous challenges, including climate change, declining soil fertility, and the emergence of pests and diseases (Saleem et al., 2024).

Corn is an agricultural crop that is widely cultivated after wheat and rice in terms of cultivation area worldwide, and it occupies a significant position in the food industry (Zhang et al., 2018). In addition to its

application in food production, the crop has a wide range of uses, including in the manufacture of animal feed, biofuel and industrial raw materials. It is evident that, owing to its elevated nutritional value and extensive range of applications, the crop occupies a pivotal position within the domain of global agriculture (Erenstein et al., 2022). However, the yield of Corn is subject to the influence of a variety of environmental and biological factors. In particular, foliar diseases, which are prevalent in Corn plants, have been shown to result in significant losses in production and to have a detrimental effect on agricultural productivity (Bruns, 2017; Chen et al., 2021).

Early diagnosis of plant diseases is imperative for minimising losses in agricultural production and ensuring sustainable yield. Conventional agricultural practices typically rely on observational methods for disease detection, but these approaches are susceptible to human error and often require a considerable time investment (Mehta et al., 2023). Incorrect or delayed diagnoses of diseases have the potential to result in producers utilising chemical pesticides in excess or in insufficient amounts. This situation gives rise to both economic losses and environmental problems. Consequently, the utilisation of more sophisticated and automated systems has become imperative in the domain of agricultural disease diagnosis (Megersa et al., 2023).

In recent years, information technologies such as artificial intelligence and machine learning have emerged as significant areas of research and development.

The objective of this study is to comparatively evaluate the performance of different convolutional neural network (CNN) architectures in the image-based classification of corn leaf diseases. Within the scope of the study, widely used CNN models—namely AlexNet, GoogLeNet, ResNet, DenseNet, EfficientNet, MobileNet, and ConvNeXt—were employed for the classification task. The performance of each model was analyzed using evaluation metrics such as accuracy, F1-score, precision, and ROC-AUC. Accordingly, the study aims to identify the most suitable deep learning architecture that can contribute to the development of artificial intelligence-based diagnostic systems in the field of agriculture.

MATERIALS AND METHODS

The dataset utilised in the present study was obtained from the Kaggle platform and comprises 4188 labelled images, encompassing the following classes: Common Rust (1 306 images, Figure 1), Gray Leaf Spot (574 images, Figure 2), Blight (1146 images, Figure 3) and Healthy (1162 images, Figure 4). The data is segmented into 80% for training, 10% for validation, and 10% for testing. The training was executed within the Google Colab environment, utilising the Python programming language and TensorFlow/Keras libraries. All CNN models (AlexNet, GoogLeNet, ResNet, DenseNet, EfficientNet, MobileNet and ConvNeXt) were trained by means of the transfer learning method. Each model was run for 10 epochs.

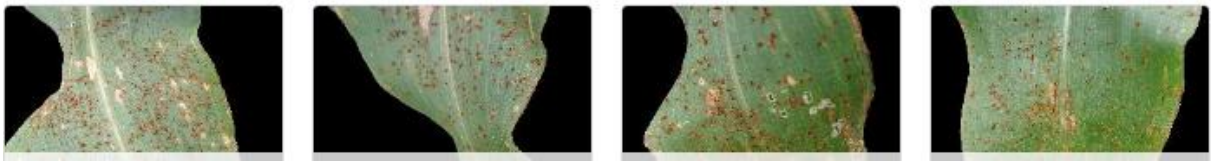

Figure 1. Examples of the common rust disease images contained within the dataset.

Figure 2. Examples of grey leaf spot disease images contained within the dataset.

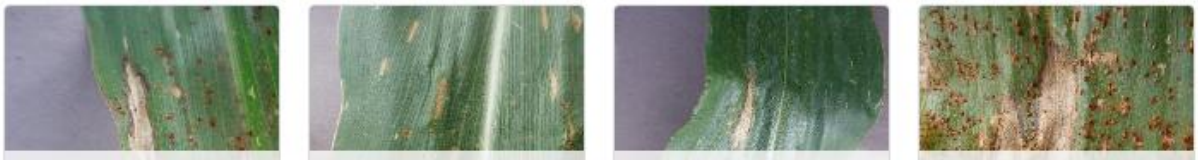

Figure 3. Examples of leaf blight disease images contained within the dataset.

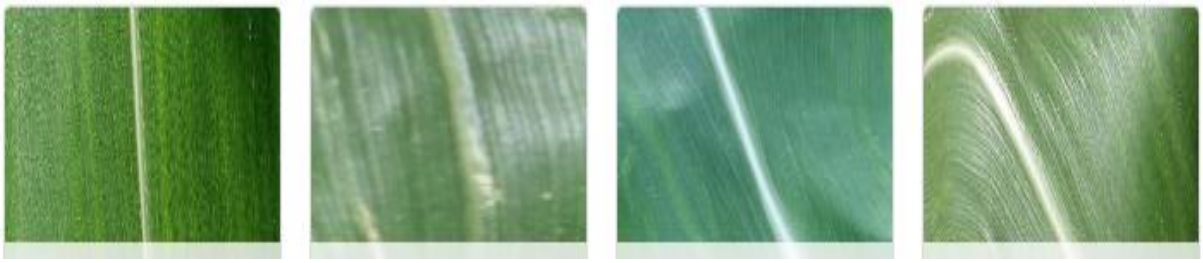

Figure 4. Examples of healthy Corn leaf images found in the dataset

The performance of the model was evaluated based on several metrics, including accuracy, precision, the F1 score, and the ROC curve (AUC).

Accuracy

The term 'accuracy' is a widely used metric for evaluating the performance of a classification model. The term is most commonly defined as the ratio of correct predictions to the total number of predictions. In summary, the precision of a model is calculated as the percentage of instances that it correctly classifies.

Accuracy=(True Positive + True Nagative)/(Total Number of Predictions) (Eq 1.).

Precision

It is a concept that evaluates the overall performance of a model in the context of machine learning and deep learning. It is usually calculated using accuracy and loss values. Precision indicates how well the model generalises, i.e. how effectively it can apply the knowledge learnt from the training dataset to new, unseen data.

Precision= True Positive /(True Positive + False Positive) (Eq.2).

F1-score

This metric is of significant importance in the evaluation of the performance of a model in machine learning, particularly in the context of classification problems. The F1 score is a metric that calculates the equilibrium between precision and recall. Precision and recall seek to achieve equilibrium between false positive and false negative predictions of a model, a strategy that is especially beneficial in the context of imbalanced datasets.

Calculation:

Precision and recall are frequently considered to be opposing objectives; enhancing one may concomitantly diminish the other. The F1 score provides an overall measure of performance by balancing these two metrics. The F1 score is calculated using the harmonic mean.

F1=2 x (Precision x Recall)/(Precision+Recall) (Eq 3.).

ROC curve

The Receiver Operating Characteristic (ROC) curve is a tool employed for the evaluation of the performance of classification models. Its employment is most prevalent in the context of two-class classification problems. The analysis of the ROC curve facilitates the observation of the alterations in the true positive rate (TPR) and false positive rate (FPR) of the model across varying thresholds.

The following steps are to be taken in order to conduct ROC curve analysis:

The following definition of axes is provided:

Y-axis (TPR - True Positive Rate): The proportion of samples that are correctly classified as positive by the model. This is also referred to as 'sensitivity'.

TPR=(True Positive)/(True Positive+False Negative) (Eq 4.).

X-axis (FPR - False Positive Rate): The proportion of samples that the model incorrectly classifies as positive. Also known as “1 – specificity”.

FPR=(False Positive)/(False Positive+True Nagative) (Eq 5.).

Interpretation of ROC Curves

A ROC curve is a graphical representation of the relationship between true positive rate (TPR) and false positive rate (FPR) as a function of threshold. The curve is a representation of the model's capacity for

discrimination. When the ROC curve is closer to the upper left quadrant, indicating a high TPR and low FPR, the model performs optimally.

The ideal model: The ROC curve for this model is closest to the point (0,1), i.e. the false positive rate is 0 and the true positive rate is 1.

Random forecasting model: The ROC curve for this model is a diagonal line with a 45° inclination, as the model makes random predictions for both classes.

Area Under Curve (AUC) Score

The AUC score is a metric used to assess the performance of a diagnostic test. The AUC is a metric that encapsulates the overall performance of a model by way of a single number. In the event of the AUC score approximating 0.5, the model is hypothesised to be predicting randomly. It is evident that the closer the AUC score is to 1, the superior the model's performance is deemed to be.

When the AUC is equal to 1.0, the model is considered to be a perfect model. If the AUC is 0.5, the model is considered to be a random prediction model. If the AUC is greater than 0.7, the model is considered to be significantly better than a random prediction. The model in question has been demonstrated to demonstrate high performance, with an AUC greater than 0.9.

The shape of the curve facilitates comprehension of the classifier model's efficacy at varying thresholds. Should the ROC curve demonstrate a rapid upward trend, remaining in close proximity to the left, it can be deduced that the model is accurately predicting positives and effectively minimising false positives.

RESULTS AND DISCUSSION

In this study, the performances of seven different CNN architectures in classifying Corn leaf diseases were analysed. In terms of accuracy, precision, F1 score and ROC-AUC metrics. Table 1 summarises the main performance measures obtained by all the models.

Table 1. Performance criteria demonstrated by models in the classification of leaf diseases of maize

Model Name	Accuracy (%)	Precision	F1 Score	AUC average Values
AlexNet	90.3	0.88	0.89	0.975
GoogLeNet	91.5	0.90	0.91	0.965
ResNet	93.2	0.92	0.93	0.967
DenseNet	95.1	0.94	0.95	0.970
EfficientNet	94.3	0.91	0.94	0.957
MobileNet	92.0	0.90	0.91	0.960
ConvNeXt	96.4	0.95	0.96	0.980

As illustrated in Figure 5, a performance comparison of these seven distinct CNN models is presented in terms of accuracy, precision, and the F1 score. In all models, the accuracy rate is consistently high, generally at the level of 1.0. However, it should be noted that the precision and F1 score values vary according to the model. The ConvNeXt model demonstrated the most optimal performance in terms of F1 score and precision. DenseNet and EfficientNet models also attracted attention with similarly elevated F1 scores. Conversely, the AlexNet, GoogLeNet and MobileNet models demonstrated the poorest performance in terms of F1 score. Conversely, the ResNet model exhibited a moderate degree of success. The results indicate that the classification accuracy of the models is generally high, but there are significant variations in the metrics.

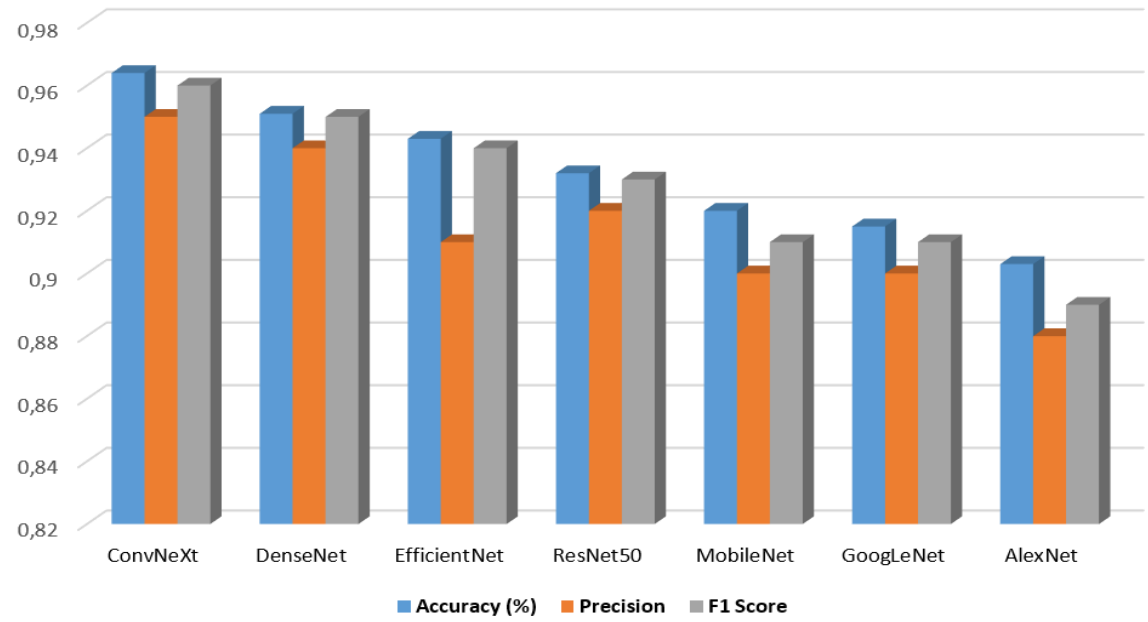

Figure 5. Comparison of CNN models in terms of accuracy, precision and F1-score.

As illustrated in Figure 6, the comparative AUC scores of seven distinct CNN models for four classes (Blight, Common Rust, Gray Leaf Spot, Healthy) are demonstrated. It was generally observed that all models attained the highest AUC scores in the 'Healthy' class. The EfficientNet, ConvNeXt and DenseNet models demonstrate superior overall performance and consistency between classes. The EfficientNet model has been observed to generate considerable interest, with the AUC scores demonstrating a high degree of proximity to 1.0, particularly within the 'Healthy' and 'Common Rust' classes. In contrast, the AlexNet and GoogLeNet models exhibited lower AUC values compared to other models, demonstrating substantial declines, particularly in the 'Gray Leaf Spot' category. In contrast, MobileNet and ResNet demonstrated moderate performance, yielding relatively higher AUC scores in the 'Blight' and 'Common Rust' classes. The results demonstrate that there are discrepancies in model performance between classes, with some models exhibiting superior prediction efficacy in specific classes.

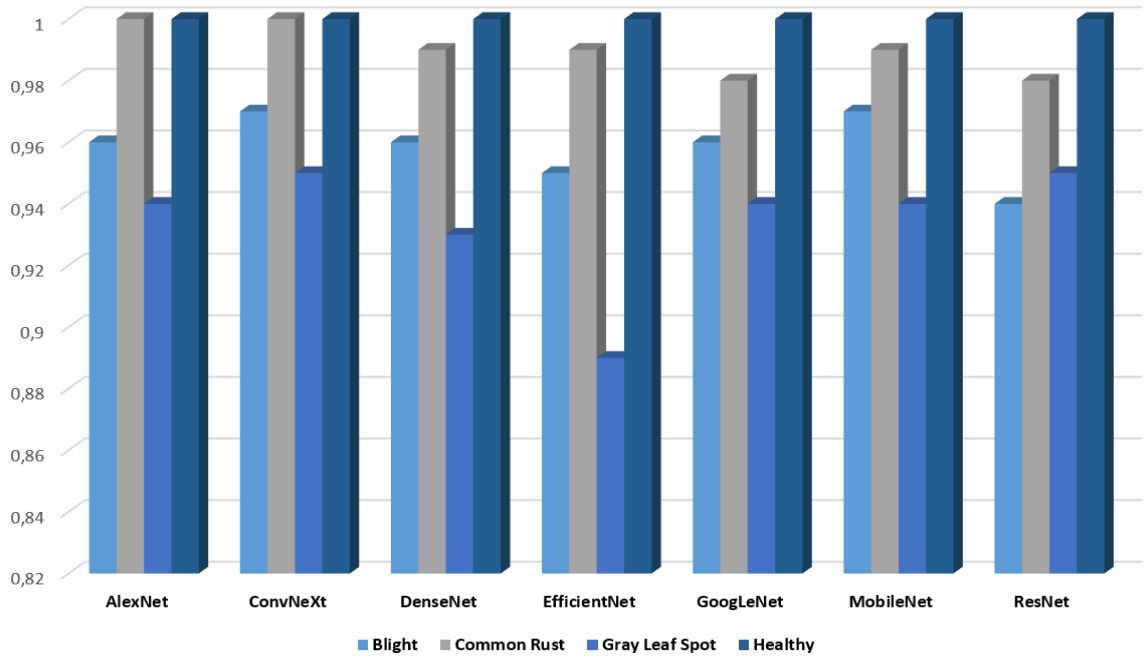

Figure 6. AUC values of CNN models on the ROC curve by class.

In this study, the performances of different CNN-based architectures in the classification of plant diseases were evaluated based on fundamental metrics such as accuracy, precision, F1 score and AUC. The results indicate that the ConvNeXt model demonstrated superior performance in both general success metrics and class-based AUC analysis when compared to other models. Specifically, it attained the highest values, with 96.4% accuracy, 0.95 precision, 0.96 F1 score and 0.980 AUC average. This result suggests that this architecture can learn visual differences in plant leaves with greater effectiveness. It is noteworthy that the DenseNet and EfficientNet models emerged as noteworthy alternatives, exhibiting a high degree of accuracy and an F1 score that is comparable to that of the top-performing models. However, the relatively lower AUC average in the EfficientNet model suggests that the discrimination between classes may have decreased in some classes.

In the class-based AUC analysis, it is noteworthy that the models generally demonstrated the highest success in the 'Healthy' class. This result suggests that healthy leaves exhibit clearer visual characteristics in comparison to diseased leaves. Conversely, the 'Gray Leaf Spot' category exhibited lower AUC values, particularly in relatively aged architectures such as AlexNet and GoogLeNet. This result suggests that the capacity of older networks to discern fine details may be constrained. Indeed, as Wei et al. (2022) have reported, architectures enhanced in depth have been shown to achieve higher levels of generalisation in the classification of plant diseases.

The observation that lightweight networks such as MobilNet and GoogLeNet can attain satisfactory accuracy and AUC values despite their modest hardware requirements indicates the potential suitability of these models for mobile applications or edge devices (Howard et al., 2017).. This finding underscores the necessity for decision support systems operating in the field to strike a balance between energy efficiency and accuracy.

In conclusion, this study demonstrates that the ConvNeXt architecture is a strong candidate for the automatic diagnosis of plant diseases due to its high accuracy and discriminative power between classes. However, it is imperative to consider factors such as class balance, application context (i.e. mobile or laboratory) and system resources when selecting a model. In future studies, the performance of these architectures in real-time applications and their generalisation capacity in different data sets can be investigated in detail. As illustrated in Figure 7, the learning curve of the ConvNextNet model is demonstrated, while Figure 8 presents the ROC curves.

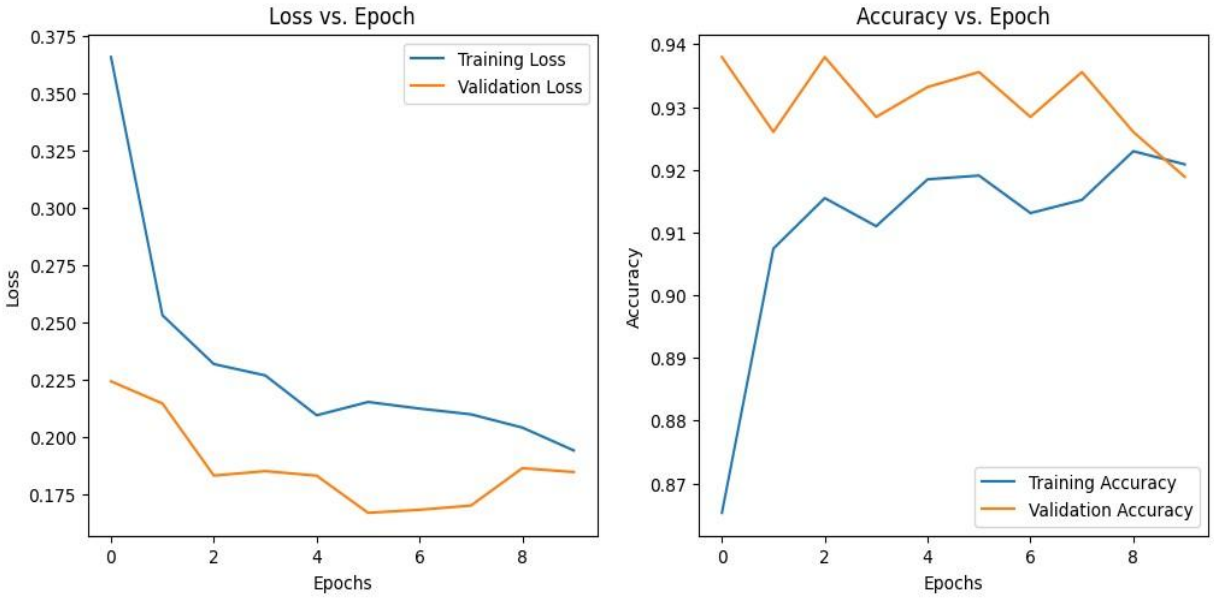

Figure 7. Learning curve of ConvNeXt Model

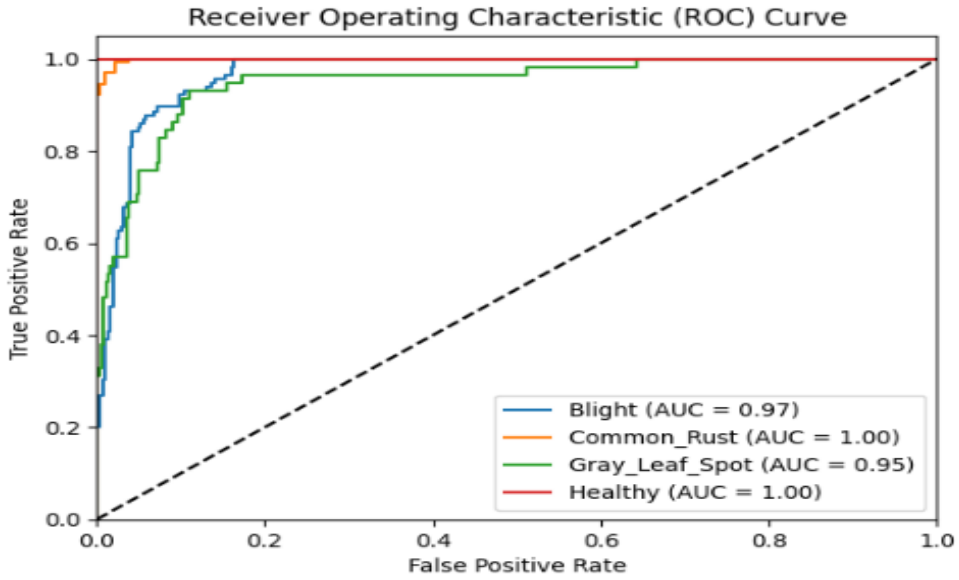

Figure 8. ROC curve of the ConvNeXt Model

CONCLUSION

This study presents a comparative evaluation of various deep learning-based convolutional neural network (CNN) architectures for classifying diseases observed in corn leaves. The models were evaluated using commonly accepted performance metrics such as accuracy, precision, F1 score, and AUC to determine their relative effectiveness in identifying plant diseases.

Among the various architectures examined, ConvNeXt achieved the highest performance across all evaluation criteria. It demonstrated notable advantages, particularly in class-based AUC analysis, by offering both strong overall accuracy and consistent differentiation between disease categories. However, other modern architectures such as DenseNet and EfficientNet also yielded competitive results, particularly in terms of F1 score and overall classification performance, highlighting their continued importance in such tasks.

On the other hand, lightweight models such as MobileNet and GoogLeNet, despite their computational efficiency and ability to achieve acceptable overall accuracy, have shown limitations in class-specific performance, particularly in the detection of diseases such as Grey Leaf Spot. Here, lower AUC values indicate weaker discriminative power. These results highlight the importance of considering both model efficiency and diagnostic accuracy when selecting architectures for use in resource-constrained environments.

In conclusion, the findings demonstrate the strong potential of deep learning-based CNN models for plant disease classification. In particular, ConvNeXt emerged as the most balanced and generalisable model among those tested and has become an attractive option for implementation in real-world decision support systems used in agricultural settings (Liu et al., 2022). However, the promising results of other architectures indicate that model selection should be tailored to the specific constraints and requirements of the intended application.

In future studies, these models should be tested on datasets composed of images captured under real-world field conditions to better evaluate their robustness and practical applicability. Additionally, ensemble or hybrid modelling approaches can be developed to address class imbalance. Such systems can contribute to improving both accuracy and stability (Ciran & Özbay, 2022).

All models were trained using fixed hyperparameters and a limited number of training epochs. While this approach does not aim to maximize the individual performance of each architecture, it provides a consistent foundation for fair comparison. The findings offer a valuable starting point for future research focused on model customization, dataset structure analysis, and real-world deployment readiness.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

Adnan GÖKTEN **:**Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; writing— original draft; writing—review and editing.

Erkut TEKELİ **:**Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; writing— original draft; writing—review and editing.

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Original Article

The Impact of Green Economy Approaches on Marketing in The Sugar and Confectionery Industry: The Case of Konya Province

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ABSTRACT

This study examines the approach of the Turkish sugar and confectionery industry to green economy practices and their relationship with marketing strategies. Covering enterprises operating in Konya province, the study analyzes attitudes towards environmentally friendly technologies and sustainability-based transformations. The sector has an important place in the Turkish food industry and is more closely associated with green economy principles in line with increasing environmental pressures. Within the scope of the research, a survey was conducted with 51 enterprises selected by proportional sampling method from a population of 107 enterprises. The questionnaire form includes the structural characteristics of the enterprises, their attitudes towards green economy practices and the factors affecting these practices. Data were collected using Likert scale and evaluated by factor and regression analyses. The findings show that the sector has a significant sensitivity towards waste management and recycling, but there is room for improvement in supply chain sustainability. It was also found that green production practices have positive effects on marketing strategies. In this context, the study provides strategic findings that can contribute to Turkey's green economy goals.

Key words: Green Economy, Marketing Strategies, Sugar and Sugary Products Industry, Sustainability.

Şeker ve Şekerleme Endüstrisinde Yeşil Ekonomi Yaklaşımlarının Pazarlamaya Etkisi: Konya İli Örneği

ÖZ

Bu araştırma, Türkiye'deki şeker ve şekerli mamuller sanayisinin yeşil ekonomi uygulamalarına yaklaşımını ve bu uygulamaların pazarlama stratejileriyle ilişkisini incelemektedir. Konya ilinde faaliyet gösteren işletmeleri kapsayan çalışmada, çevre dostu teknolojilere ve sürdürülebilirlik temelli dönüşümlere yönelik tutumlar analiz edilmiştir. Sektör, Türkiye gıda sanayisi içinde önemli bir yere sahiptir ve artan çevresel baskılar doğrultusunda yeşil ekonomi ilkeleriyle daha yakından ilişkilendirilmektedir. Araştırma kapsamında, 107 işletmelik evrenden oransal örnekleme yöntemiyle seçilen 51 işletmeyle anket çalışması gerçekleştirilmiştir. Anket formu; işletmelerin yapısal özelliklerini, yeşil ekonomi uygulamalarına yönelik tutumlarını ve bu uygulamaları etkileyen faktörleri içermektedir. Veriler, Likert ölçeği kullanılarak toplanmış; faktör ve regresyon analizleriyle değerlendirilmiştir. Bulgular, sektörün atık yönetimi ve geri dönüşüm konularında belirgin bir duyarlılığa sahip olduğunu, ancak tedarik zinciri sürdürülebilirliğinde gelişime açık alanlar bulunduğunu göstermektedir. Ayrıca çevreci üretim uygulamalarının pazarlama stratejileri üzerinde pozitif etkiler yarattığı saptanmıştır. Bu bağlamda çalışma, Türkiye'nin yeşil ekonomi hedeflerine katkı sağlayabilecek stratejik bulgular sunmaktadır.

Anahtar kelimeler: Yeşil Ekonomi, Pazarlama Stratejileri, Şeker ve Şekerli Mamuller Sanayi, Sürdürülebilirlik.

INTRODUCTION

Sugar beet production, which is of strategic importance worldwide, plays a critical role in the food industry sector in Turkey. The sugar and sugary products industry continues to be a leading sector in development with the added value it creates (Erdinç, 2017). When the historical development of sugar is examined, it is seen that it started with sugar cane in India in the 4th century BC and spread to different geographies over time. Today, sugar is obtained from both sugar cane and sugar beet, and although the structure of sugar produced from both sources is sucrose, small differences are observed in their crystal structures (Elgün, 2013; Topak, 2007; Demirel and Akdeniz , 2019).

Since the early years of the Republic, the sugar factories established in Turkey have both met domestic market needs and created an industrial branch with export potential. The number of factories that started operations in Alpullu and Uşak in 1926 reached 33 over time, with annual sugar production reaching approximately 1.6 million tons. Today, however, the food industry is evaluated not only in terms of production capacity, but also in terms of sustainability-based transformation; environmental pollution, climate change, and global crises are leading sectors to new searches.

In this process, the concepts of “green economy” and “green technology” have come to the forefront, and the concept of environmentally friendly production and sustainable living has started to be adopted, especially in the food sector. The green economy has taken its place in the literature as a holistic growth model that aims to reduce interest rate risk, increase social welfare, and ensure social equality (Güneş, Keskin and Kıymaz, 2014). Various studies have analyzed the aspects of this model in terms of reducing environmental risks and strengthening social justice (Akyazı and Korkmaz, 2024) . The main starting point of the green economy is that it offers a solution to the unconscious consumption of natural resources, environmental pollution, and excessive production-consumption imbalance. The food sector is also directly affected by this transformation.

Although green practices are becoming widespread in Turkey, the desired level has not yet been reached. For example, Renings (2000) and OECD (2011) emphasize that green technologies are effective in solving environmental problems and support the goal of leaving a clean environment. Since the agricultural sector provides the main input for the food industry, the integration of these two sectors in the context of the green economy is important. Although green technologies are used in food processing processes, if raw material supply does not comply with the same principles, the sustainability chain remains incomplete (Erdinç, 2017).

Public support and international cooperation play a decisive role in the transition to a green economy. Green investments and incentives for organized industrial zones in Turkey contribute to sustainability. The Turkey Organized Industrial Zones Project is one of these examples (Esenlikci, 2023). In line with the increasing global population and sustainability requirements, green economy practices are no longer a choice but a necessity for sectors (Nalinci, 2023).

The green economy model offers multidimensional outputs such as economic growth, employment growth, and social equality, not just environmental sensitivity. Targets such as reducing carbon emissions, using clean energy, and protecting biodiversity are also within the scope of this model. In this context, the sugar and sugary products industry also aims to make social and environmental contributions by developing sustainable production models (Doğan, 2022; Ağcakaya and Kaya, 2022).

In this study, the approaches of sugar and confectionery industry enterprises operating in Konya province towards the green economy and the relationship between these approaches and marketing strategies were evaluated. The aim of the research is not only to analyze the environmental sensitivity of the enterprises but also to reveal how this sensitivity is reflected in their economic performance, market expansion strategies, and competitiveness. In this framework, we focused on the following basic question:

• What are the perspectives of the enterprises producing sugar and sugary products in Konya province industry towards green economy practices?

As a result of the interviews conducted to answer this question, the following specific objectives were achieved:

• The perspectives of confectionery enterprises in Konya towards green economy practices were analyzed.

• Factors encouraging or hindering the practices were identified.

• The relationships between marketing areas and green economy sensitivity were evaluated.

MATERIALS AND METHODS

The main material of this study consists of primary data obtained through interviews with the managers of sugar and confectionery industry enterprises operating in Konya province. According to the NACE Rev.2

classification system adopted by the Union of Chambers and Commodity Exchanges of Turkey (TOBB), this sector is categorized under the food manufacturing industry. Specifically, sugar manufacturing is classified under Code 1081 – Manufacture of sugar, and confectionery production is classified under Code 1082 – Manufacture of cocoa, chocolate, and sugar confectionery (Özaydın and Çelik, 2022).

The population of the research consists of a total of 107 sugar and sugar-sweetened products enterprises operating in Konya province, which are included in TOBB records. Considering the current situation of these enterprises, the number of enterprises to collect data was calculated by the proportional sampling method. The sample size was determined by the proportional sampling formula proposed by Newbold (1995); since the level of green economy attitudes in the universe is unknown, the assumption of p=0.5 was made to maximize the sample size. As a result of the calculations made with a 95% confidence level (Z=1.96) and a 10% margin of error, the number of enterprises to be interviewed was determined as 51.

Sampling Formula:

$$n = \frac{N * p(1-p)}{(N-1) * \sigma_x^2 + p(1-p)}$$

In the formula;

n: Sample volume,

N: Total number of people in the sampling frame,

p: Number of enterprises with a high level of green economy implementation (based on a 50% assumption),

σ_x^2: Variance of the proportion (table value 1.96 with 95% confidence interval and 10% margin of error to reach the maximum sample volume).

The questionnaire form, prepared as a data collection tool, consists of questions to measure the socio-demographic characteristics, marketing structures, and green economy perspectives of the operators. Socio-demographic and marketing data were evaluated by frequency and percentage analysis and presented in tables.

Data on socio-demographic characteristics and marketing structures of the research were analyzed by calculating frequencies and percentages and presented in tables. In order to measure the perspectives of enterprises towards green economy practices, a scale was developed in line with the studies conducted by Güneş et al. (2014), Doğan (2022), Nalinci (2023), Ağcakaya (2022), and Esenlikci (2023). The questions in the questionnaire form were Likert scale questions (5: Strongly Agree, 4: Agree, 3: Undecided, 2: Disagree, 1: Strongly Disagree) (Tezbaşaran, 2017). Validity and reliability analyses were conducted on this scale applied to measure green economy perspectives, and confirmatory factor analyses were conducted. Confirmatory factor analysis (CFA) is an analysis method that is frequently used in the development of measurement models and provides significant convenience. This method is a process of creating latent variables (factors) based on observed variables through a previously created model. It is generally used in scale development and validity analysis or aims to verify a predetermined structure (Yaşlioğlu, 2017).

A multiple linear regression model was used to determine the effect of business managers' perspectives on the green economy on the marketing areas of businesses. One of the methods used to estimate the effect of the dependent variable on the independent explanatory variables is the linear regression model. If the independent variable is made with one variable, simple linear regression is used, and if there is more than one variable, a multiple regression model is used. In order to test the appropriateness and significance of the variables obtained in regression analysis, the t-test value and the determination coefficient are used, depending on the correlation coefficient. The “t” test shows the interaction between dependent and independent variables, and the coefficient of determination shows the strength of this interaction. The coefficient of determination is found by squaring the correlation coefficient (R2) (Gujarati, 2009). Within the scope of the study, while the marketing areas of the enterprises (Regional, National, and International) will be the dependent variable, the factors obtained from the business managers' perspectives on the green economy will constitute the independent variables. In this way, the green economy perspectives that are effective in the marketing area of the enterprises will be determined.

RESULTS AND DISCUSSION

In this section, the data obtained from the field study conducted with sugar and confectionery industry enterprises operating in Konya province are analyzed. The findings are presented under four subheadings: socio-

demographic characteristics of enterprises, marketing areas, perspectives on green economy, and the effect of marketing areas on green economy attitudes. The data are interpreted with frequency and percentage distributions, and the presentation of the analyses is supported by tables and explanatory texts.

The majority of the managers of the enterprises in the sugar confectionery sector participating in the research are men. When the distribution according to enterprise scale is analyzed, it is seen that the rate of female managers is very low in small and medium-sized enterprises (SMEs), and there are no female managers in large enterprises. Overall, 92.15% of managers are male and only 7.84% are female. This shows that a gender-based imbalance prevails in the sector and that women's representation remains at very low levels. Indeed, a similar situation coincides with studies indicating that women's employment in the food industry is generally limited to lower levels (FAO, 2019; EIGE, 2021; Acar and Ergen, 2021). It is stated that women entrepreneurs are located in service or retail sectors rather than production industries (Arslan and Acar, 2021).

The average age of the participants differs according to the scale of the enterprises. While the average age is 48.17 in micro enterprises, it is 39.76 in medium-sized enterprises and 52 in large-scale enterprises. This distribution reveals that the management of the sector is largely carried out by young and middle-aged individuals.

When the distribution according to education level was examined, it was determined that 42.55% of the managers were primary school graduates, 34.04% were high school graduates, 6.38% were associate degree graduates, 12.76% were bachelor's degree graduates, and 4.25% were master's degree graduates. It was observed that, especially in large-scale enterprises, there were managers with bachelor's and master's degrees, whereas in micro and small-scale enterprises, the basic education level was predominant. This situation shows that the education level tends to increase as the scale of the enterprise increases.

Table 1. Socio-Demographic Characteristics of Sugar and Sugary Products Industry Business Managers

Characteristic	0–9 Employees	10–49 Employees	50–249 Employees	250+ Employees	Total (%)
Gender					
Male (%)	91.66	88.23	100.00	100.00	92.15
Female (%)	8.34	11.76	-	-	7.84
Average Age	48.17	39.76	50.5	52.00	-
Education Level					
Primary School (%)	58.33	23.52	33.33	-	42.55
High School (%)	20.83	47.05	16.66	50.00	34.04
Associate Degree (%)	-	11.76	16.66	-	6.38
Bachelor's Degree (%)	4.16	11.76	33.33	25.00	12.76
Master's Degree (%)	-	5.88	-	25.00	4.25

When we look at the fields of activity of the sugar and sugary products industry enterprises participating in the research, it is seen that most enterprises operate in more than one market (Table 2). 31.37% of the enterprises operate in local, national, and international markets at the same time. This is followed by enterprises operating only in local and national, with 15.68%, national and international, with 15.68%, and local and international, with 11.76%. The rate of enterprises operating only in the local market is 11.76%, the rate of enterprises operating only in the national market is 9.80%, and the rate of enterprises operating only in the international market is 3.92%.

This distribution shows that most of the enterprises in the sugary products sector are not limited to a single market, especially medium and large-sized enterprises operate in multiple markets and tend to wider markets. It is stated that enterprises with a wide marketing area are in a more strategic position in terms of gaining competitive advantage, product differentiation, and branding in foreign markets (Demir and Kılıc, 2022; Güngör and Atesoglu, 2020).

When we look at the employment data, the average personnel is calculated as 5.75 in micro-scale enterprises, 23.47 in small-scale enterprises, 89.33 in medium-scale enterprises, and 305.25 in large-scale enterprises. These data show that especially large-scale enterprises are more advantageous in implementing strategies that require human resources, such as green transformation, foreign trade, and multi-channel marketing (Uçar and Küçük, 2020; Demirtaş, 2023).

Table 2. Fields of Activity of Sugar and Sugary Products Industry Enterprises

Operatianal Area	0 – 9	%	10–49	%	50–249	%	250 +	%	Total	%
Local	5	83.33	1	16.67	–	–	–	–	6	11.76
National	4	80.00	1	20.00	–	–	–	–	5	9.80
International	2	100.00	–	–	–	–	–	–	2	3.92
Local+National	4	50.00	4	50.00	–	–	–	–	8	15.68
Local+International	3	50.00	3	50.00	–	–	–	–	6	11.76
National+International	3	37.50	3	37.50	2	25.00	–	–	8	15.68
All Market Segments	3	18.75	5	31.25	4	25.00	4	25.00	16	31.37
Total	24	47.06	17	33.33	6	11.76	4	7.84	51	100.00
Number of Employees	–	5.75	–	23.47	–	89.33	–	305.25	–	–

The level of knowledge and attitudes of the enterprises operating in the sugar and sugar-sweetened products sector regarding green economy practices were evaluated by means of explanatory factor analysis (EFA). This analysis revealed which areas the enterprises focus on more by grouping their green economy perspectives approaches.

Table 3. Attitudes of Sugar and Confectionery Industry Managers Towards Green Economy Approaches

Factors	Scale Items		Factor Loadings	Mean	Variance Explained (%)
Waste Management and Recycling	We ensure the recycling of waste generated during production.	1	0.887	2.47	
	We have long-term plans aligned with the zero-waste target.	2	0.823	2.08	
	We ensure the disposal of hazardous waste without harming the environment.	3	0.797	2.06	
	We use packaging materials with high recycling rates.	4	0.725	2.43	
	We develop new methods for the reuse or transformation of waste.	5	0.705	2.98	
	We use recyclable or eco-friendly raw materials in our products.	6	0.475	3.51	18.263
Production Processes and Resource Management	We gain a competitive advantage through green practices.	7	0.817	2	
	Green economy practices reduce our operational costs.	8	0.805	2.37	
	Environmental sensitivity increases our brand value.	9	0.741	3.63	
	We take measures to reduce carbon emissions in our production processes.	10	0.542	3.51	15.511
Corporate Governance and Social Responsibility	We organize training programs to increase our employees' environmental awareness.	11	0.832	2.24	
	We carry out social responsibility projects to raise public environmental awareness.	12	0.806	2.67	
	We benefit from government incentives for environmentally friendly practices.	13	0.635	2.12	
	We have a corporate culture that supports green economy practices.	14	0.598	2.18	
	Environmentally friendly production practices increase customer satisfaction.	15	0.529	2.27	15.497
Environmental Benefits and Firm Performance	Environmental sustainability holds an important place in our corporate strategy.	16	0.778	1.98	
	We make continuous investments to increase energy efficiency.	17	0.720	1.98	
	We implement innovative methods to reduce water consumption.	18	0.645	1.88	
	We use technologies that provide energy savings in production processes.	19	0.563	1.82	13.626
Material and Supply Chain Manage	We consider sustainability criteria when selecting suppliers.	20	0.762	1.78	
	We prioritize working with green-certified suppliers.	21	0.750	1.65	10.102
Cumulative Variance Explained					72.999
Kaiser-Meyer-Olkin (KMO) Sampling Adequacy					0.642
Bartlett's Test of Sphericity:		**Chi-Square**			803.424
		df			210
		p-value			.000

As a result of the analysis, a total of 21 statements were grouped under five factors, and this quintet structure explained 72.999% of the total variance (Table 3). The Kaiser-Meyer-Olkin (KMO) sampling adequacy

coefficient, which was applied to test the suitability of the data before factor analysis, was found to be 0.642; this value indicates that the sample is sufficient for the analysis. In addition, Bartlett's Test of Sphericity was significant (Chi-Square=803,424; sd=210; p<0.001), which indicates that there is a significant relationship between the variables and factor analysis is appropriate.

The highest factor loadings were observed in the statements "We recycle the wastes generated during production" (load=0.887) and "We ensure that hazardous wastes are disposed of without harming the environment" (load=0.797). This shows that the sector's most intensive practice in environmentally sensitive production is in the field of waste management.

Considering the mean values, the statements "We use environmentally friendly raw materials in our products" and "We take measures to reduce carbon emissions in our production processes" have relatively high means of 3.51. On the other hand, some statements, such as "We care about working with green-certified suppliers," have a low mean value of 1.65. This shows that some green practices are still not widespread across the sector.

In this section, the effects of marketing areas of enterprises on their perspectives on the green economy were analyzed with a multiple linear regression model (Table 4). While marketing areas were taken as the dependent variable, the independent variables were the responses of enterprises to five factors related to green economy practices.

According to the results of the analysis, the overall significance of the model was achieved (F=5.501; p<0.01). The Durbin-Watson coefficient of 1.761 indicates that there is no dependence problem. According to the regression results, only two of the green economy factors of marketing areas were found to be statistically significant: Waste Management and Recycling (p=0.000): It is the variable with the strongest and most significant effect (β=0.529). This shows that businesses emphasize environmentally friendly waste management practices in their marketing strategies and that this area is decisive in achieving competitiveness. Materials and Supply Chain Management (p=0.014): It shows a negative and significant effect (β=-0.302). This suggests that sustainable procurement practices have not yet made a positive contribution to marketing processes or that businesses have not yet achieved sufficient integration in this area. The other three factors (Production Processes and Resource Management, Corporate Governance and Social Responsibility, Environmental Benefits and Firm Performance) did not show a significant effect on the marketing area (p>0.05). These findings reveal that waste management is the most direct contributor to marketing success among environmental practices. These findings are consistent with studies in the literature which emphasize the strategic importance of waste management in green marketing. For instance, Youn and Kim (2022) highlight that recycling-oriented practices not only reduce operational costs but also enhance customer loyalty and environmental brand value. Similarly, Martínez (2015) suggests that eco-conscious strategies such as zero-waste initiatives can lead to long-term trust-based customer relationships, ultimately supporting competitive positioning.

Table 4. Results of Regression Analysis Between Marketing Fields and Green Economy Factors

Variables	B	Standard Error	Beta Coefficient	t	Sig.
Constant	2.196	.101		21.652	.000
Waste Management and Recycling	.462	.102	.529	4.508	**.000**
Production Processes and Resource Management	-.026	.102	-.030	-.252	.802
Corporate Governance and Social Responsibility	-.061	.102	-.070	-.600	.552
Environmental Benefits and Firm Performance	.040	.102	.046	.395	.695
Material and Supply Chain Management	-.263	.102	-.302	-2.570	**.014**
Durbin-Watson: 1,761 **R2:** 0,379	**df:** 5	**p<0,01**	**F:** 5,501		

CONCLUSION

In this study, the approaches of sugar and confectionery industry enterprises operating in Konya province towards green economy practices and the effects of these approaches on marketing strategies were examined in detail. The results of the research revealed that the sector has improved in certain areas towards sustainability principles, but there is still limited progress in some areas.

Factor analysis findings show that green economy practices are evaluated by enterprises in five main dimensions: Waste management and recycling, production processes and resource management, corporate governance and social responsibility, environmental benefits and firm performance, and materials and supply chain management. Among these dimensions, waste management practices stand out as the strongest area in terms of both awareness and operational implementation. The recycling of waste generated during production,

zero waste targets, and the use of recyclable materials in packaging materials show that enterprises are aware of environmental responsibility in this area.

On the other hand, the low scores observed in the material and supply chain management factor indicate that enterprises do not make adequate plans for sustainable procurement, and that this issue remains in the background in business policies. The low average value in the statement "We care about working with green certified suppliers" indicates that there are serious gaps in the integration of the supply chain into environmentally friendly practices.

According to the results obtained from the regression analysis, only two dimensions show a significant effect in the relationship between marketing areas and green economy factors. Waste management and recycling are identified as the most important factors that positively affect marketing areas. This finding indicates that environmentally friendly production and waste management strategies contribute to the stronger positioning of enterprises in the market. Materials and supply chain management were the only factors that negatively affected marketing processes. This indicates that deficiencies in this area constitute an obstacle for businesses in terms of market expansion or sustainable branding.

In light of the research results, the following recommendations are presented:

• Waste management practices should be supported, and successful examples should be disseminated in the sector. Technical consultancy and financial incentives should be developed especially for small and medium-sized enterprises.

•Supply chain sustainability should be made a priority policy area for the sector. The accessibility of green certification processes should be increased, and companies should be guided in this regard.

•Government support should be diversified not only for production technologies, but also for organizational sustainability and corporate capacity building.

•Increasing female entrepreneurship and executive representation should be encouraged for social sustainability in the sector. Sectoral support mechanisms should be established in this area where female employment is low.

•Training and awareness programs should be expanded to increase the level of knowledge of business owners on the green economy. In particular, the effects of environmental impacts on firm performance should be explained with concrete data.

In conclusion, there is a need to develop multifaceted, inclusive, and sustainable policies for the sugar and sugar-sweetened products industry to contribute to the environmental transformation process. The findings obtained in the case of Konya province clearly show that this transformation should not only be limited to the environment, but also be a holistic structure that affects marketing, management, and competitive strategies.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

***Gürhan ÖZAYDIN*:** Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; writing—original draft; writing—review and editing.

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Original Article

Economic and Agricultural Effects of Climate Change on Forage Crop Yield in Erzurum Province: ARDL Bound Test Approach

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ABSTRACT

Climate change has become a phenomenon that significantly affects agricultural production on a global scale. Agricultural production is both affected by climate change and triggers to it through greenhouse gas emissions. Forage crop production, particularly legume forage crops, plays a critical role in both economic and environmental aspects, as it is a fundamental input for livestock farming. This study examines the relationship between forage crop yield and climate variables in Erzurum province, analyzing the long- and short-term effects of annual average temperature and total annual precipitation on forage crop yield using the ARDL bound test approach. The findings indicate that an increase in annual average temperature positively affects forage crop yield, while a decrease in precipitation has a negative impact. The results of the ARDL bound test confirm the existence of a long-term cointegration relationship between the variables. Additionally, the error correction model analysis suggests that short-term imbalances are largely corrected in the subsequent period, indicating that the system reaches equilibrium in the long run. The results demonstrate that forage crop production in Erzurum province is directly affected by climate change and that changes in climatic conditions are reshaping agricultural production processes. In this regard, promoting climate-resilient forage crop species, expanding modern irrigation techniques, improving soil and water management, adopting agricultural practices that reduce greenhouse gas emissions, and strengthening support mechanisms for producers are recommended. The findings highlight the necessity of developing regional agricultural policies that adapt to climate change.

Key words: ARDL, Climate Change, Forage Crops

İklim Değişikliğinin Erzurum İli Yem Bitkileri Verimi Üzerindeki Ekonomik ve Tarımsal Etkileri: ARDL Sınır Testi Yaklaşımı

ÖZ

İklim değişikliği, küresel ölçekte tarımsal üretim üzerinde önemli etkiler oluşturan bir olgu haline gelmiştir. Tarımsal üretim hem iklim değişikliğinden etkilenmekte hem de sera gazı emisyonları yoluyla bu süreci tetiklemektedir. Hayvancılığın temel girdilerinden biri olan yem bitkileri üretimi, özellikle baklagil yem bitkileri, çevresel ve ekonomik açıdan kritik bir öneme sahiptir. Bu çalışmada, Erzurum ilinde yem bitkileri veriminin iklim değişkenleri ile olan ilişkisi incelenmiş, yıllık ortalama sıcaklık ve yıllık toplam yağış değişkenlerinin yem bitkileri verimi üzerindeki uzun ve kısa dönem etkileri ARDL sınır testi yaklaşımı ile analiz edilmiştir. Elde edilen bulgular, yıllık ortalama sıcaklıktaki artışın yem bitkileri verimini olumlu yönde etkilediğini, ancak yağış miktarındaki azalmanın verim üzerinde negatif bir etki yarattığını ortaya koymuştur. ARDL sınır testi sonuçları, değişkenler arasında uzun dönemli bir eş bütünleşme ilişkisinin varlığını göstermiştir. Ayrıca, hata düzeltme modeli analizleri, kısa dönemli dengesizliklerin büyük ölçüde bir sonraki dönemde giderildiğini ve sistemin uzun vadede dengeye ulaştığını göstermektedir. Sonuçlar, Erzurum ilinde yem bitkileri üretiminin iklim değişikliğinden doğrudan etkilendiğini ve iklim koşullarındaki değişimlerin tarımsal üretim süreçlerini yeniden şekillendirdiğini göstermektedir. Bu doğrultuda, sürdürülebilir yem bitkileri üretimi için iklim değişikliğine dayanıklı türlerin teşvik edilmesi, modern sulama yöntemlerinin yaygınlaştırılması, toprak ve su yönetiminin iyileştirilmesi, sera gazı

emisyonlarını azaltan tarımsal uygulamaların benimsenmesi ve üreticilere yönelik destek mekanizmalarının güçlendirilmesi önerilmektedir. Elde edilen bulgular, bölgesel düzeyde tarım politikalarının iklim değişikliğine uyum sağlayacak şekilde geliştirilmesi gerektiğini ortaya koymaktadır.

Anahtar kelimeler: ARDL, İklim değişikliği, Yem bitkileri

INTRODUCTION

Over the years, the global warming trend has been steadily increasing, and it is projected to accelerate in the coming years. The rapid changes in weather conditions driven by rising temperatures place ecosystems at significant risk (Tao et al., 2006; Kanat and Keskin, 2018). The primary greenhouse gases contributing to global warming are carbon dioxide (50%), chlorofluorocarbons (22%), and methane (13%) (Zoray and Pır, 2007; Demir, 2009). Among these, carbon dioxide is considered one of the main drivers of global warming. The three major greenhouse gases resulting from agricultural activities are carbon dioxide, methane, and nitrous oxide (Smith et al., 2008; Topçu et al., 2020). In 2015, through the Paris Climate Agreement, countries acknowledged the necessity of implementing measures to prevent the global average temperature from rising by more than 2°C. According to the latest report by the Intergovernmental Panel on Climate Change (IPCC), maintaining global warming below 2°C is only achievable through significant reductions in greenhouse gas emissions.

In Türkiye, data from the Turkish Statistical Institute (TURKSTAT, 2021) indicate that 72% of the country's greenhouse gas emissions originate from the energy sector, while 13.4% come from the agricultural sector. Methane emissions, in particular, contribute significantly to environmental pollution due to their high heat-trapping potential compared to other greenhouse gases. Among agricultural emissions, carbon dioxide has a relatively minor impact on global warming. In crop production, carbon dioxide emissions remain low, as plants absorb and utilize the gas during photosynthesis. However, in agricultural operations, carbon dioxide emissions primarily arise from post-harvest processing and transportation. Similarly, nitrous oxide emissions are less impactful compared to other greenhouse gases, but improper application of nitrogen-based fertilizers is a key contributor to increased emissions (Kayıkçıoğlu and Okur, 2012).

The case is different for methane emissions. In Türkiye, 62.4% of methane emissions originate from agriculture, 19.5% from the energy sector, 18.1% from waste, and 0.03% from industrial processes and product usage. Meanwhile, 72.5% of nitrous oxide emissions are attributed to agriculture, 15.7% to waste, 8.8% to energy, and 3% to industrial processes (TURKSTAT, 2021). Within the agricultural sector, rice cultivation and livestock farming are among the primary contributors to methane emissions. Ruminant animals are significant global sources of methane emissions, mainly due to enteric fermentation and the decomposition of organic manure (Ersoy, 2017).

As the global population continues to grow, the demand and consumption of animal-derived products are increasing, further driving methane emissions and exacerbating climate change (Koyuncu and Akgün, 2017; Akyüz, 2019). Additionally, climate change directly threatens livestock production. Heat stress affects animals both directly and indirectly, increasing their susceptibility to diseases, reducing fertility, and decreasing milk production. Consequently, agricultural production is not only a contributing factor to climate change but also one of its most vulnerable sectors (Koç and Uzmay, 2016; Koyuncu and Akgün, 2017).

In recent years, a growing body of research has examined the relationship between climate change and agricultural productivity (Bayraç and Doğan, 2015). Studies have focused on the effects of temperature, precipitation, and extreme weather events on crop yields, particularly for staple crops such as wheat, maize, and rice. However, few studies have addressed the impact of climate variables on forage crops, especially in high-altitude, cold-climate regions like Eastern Anatolia. This study contributes to the existing literature by focusing specifically on forage crops, which are vital to livestock-based farming systems. Unlike previous studies that primarily rely on national or regional aggregate data, this study uses province-level data and analyzes the relationship between climate variables and forage crop yields in Erzurum—a province characterized by its harsh climatic conditions and dependence on livestock farming.

This research employs econometric time series analysis to assess the influence of climatic factors such as temperature and precipitation on forage crop productivity. This study aims to assess the impact of climate change on forage crop yield, examining the relationship between climatic variables and forage crop production in Erzurum Province.

Although several studies have investigated the impacts of climate change on agricultural production in Türkiye, most have focused on crop categories such as cereals, fruits, or vegetables (e.g., Dumrul and Kılıçarslan, 2017; Akcan et al., 2022; Duru and Parlakay, 2021). Research specifically targeting forage crops remains limited. Among the few studies available, Eştürk and Mert (2022) analyzed the effect of climate change on forage crop productivity in Ardahan and found that precipitation had a short-term impact, while temperature was not

statistically significant. Similarly, Gürbüz and Kadıoğlu (2023) examined grain production under climate stress using an ARDL approach, revealing significant environmental sensitivities. However, those studies either used broader crop categories or were conducted in different climatic zones. In contrast, this study focuses specifically on forage crops in Erzurum—a province with high-altitude, continental climatic conditions—providing an original contribution to the literature by analyzing the long- and short-term effects of climate variability on forage yield at the provincial level.

MATERIALS AND METHODS

In this study, the interaction between forage crop yield in Erzurum province and the province's annual average temperature and annual average precipitation was examined for the period 1995–2021. Forage crop yield data were obtained from the Erzurum Provincial Directorate of Agriculture and Forestry, while annual average temperature and precipitation data were sourced from the General Directorate of Meteorology.

To analyze the effects of climate change on forage crop yield in Erzurum province, the model (1) was established. In this model, FCY represents the forage crop yield in Erzurum province (kg/da), TEMP represents temperature denotes the annual average temperature (°C), and PREC represents precipitation refers to the annual average precipitation (kg/m^2). The subscript t indicates the value of each variable at time t.

$$FCY_t = \beta_0 + \beta_1 TEMP_t + \beta_2 PREC_t + \varepsilon_t \quad (1)$$

The logarithmic form of the model is represented as equation (2).

$$LFCY_t = \beta_0 + \beta_1 LTEMP_t + \beta_2 LPREC_t + \varepsilon_t \quad (2)$$

The econometric analysis consists of two stages: unit root tests and the ARDL bound test. The use of unit root tests is essential to avoid spurious regression (Raihan and Tuspekova, 2022). To determine whether the regression variables are stationary, the equations involving their differences are estimated. To ensure stationarity, the Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller (1979) and Elliott et al. (1992), as well as the Phillips-Perron (PP) test introduced by Phillips (1988), were applied. If autocorrelation is detected in the error term of the initial model specification, lagged terms are included to mitigate its adverse effects. Three different models are used in unit root testing.

$$\Delta FCY_t = \tau_1 TEMP_{t-1} + \tau_2 PREC_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta FCY_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta TEMP_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta PREC_{t-i} \quad (3)$$

The ARDL bound test can be employed when all variables are of the same order of integration, as it does not require strict assumptions. It is particularly advantageous for small sample sizes and provides accurate estimations of long-term relationships. In this context, the ARDL bound test approach is formulated as follows:

In Equation (3), Δ represents the first difference, while **q** denotes the optimal lag length.

The ARDL bound test follows the F-distribution**.** The F-test employs Ordinary Least Squares (OLS) to assess the significance of the lagged variables. The primary objective is to determine whether a long-term relationship exists between the variables.

RESULTS AND DISCUSSION

The descriptive statistical values for the variables (in logarithmic form) are presented in Table 1. The Jarque-Bera probability values indicate that smaller values confirm the normal distribution of all parameters.

Table 1. Descriptive Statistics of Variables

Variables	LFCY	LTEMP	LPREC
Mean	3.252	0.746	1.817
Median	3.332	0.741	1.822
Maximum	3.417	1.114	1.850
Minimum	2.788	0.616	1.782
Standard Deviation	0.196	0.098	0.020
Skewness (S)	-1.505	2.008	-0.140
Kurtosis (K)	3.924	8.660	1.937
Jarque-Bera	1.115	5.420	1.360
	0.004	0.000	0.507
Number of Observations	27	27	27

The correlation relationships between the variables are presented in Table 2. It is observed that forage crop yield is associated with both temperature and precipitation.

To examine the long-term relationship between forage crop yield and climate change indicators, namely average temperature and average precipitation, unit root tests (ADF and PP) were conducted. The results are presented in Table 3.

Table 2. Correlation Analysis of Variables

Variables	LFCY	LTEMP	LPREC
LFCY	1	0.140	-0.552
LTEMP	0.140	1	-0.013
LPREC	-0.552	-0.013	1

The findings indicate that forage crop yield and average precipitation become stationary at their first differences, suggesting that they are integrated of order one (I(1)). In contrast, average temperature was found to be stationary at its level, meaning it is integrated of order zero (I(0)).

Table 3. Unit Root Test Results (ADF and PP Tests)

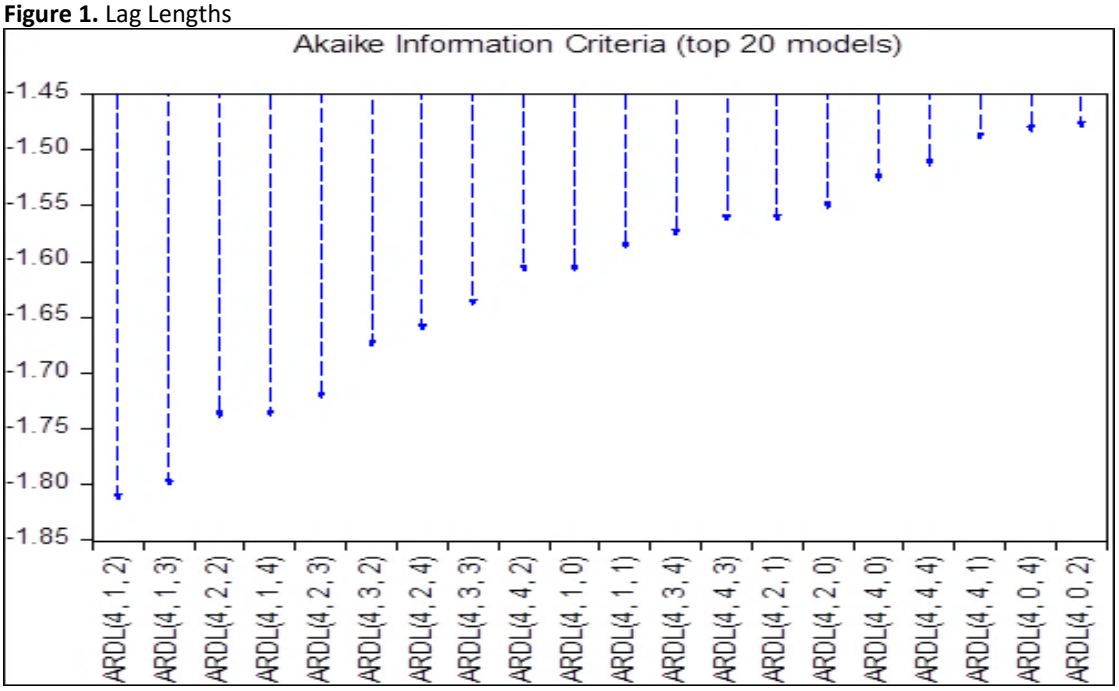
Variables	ADF	PP
Log(FCY)	-25.831	-20.140
Δ Log(FCY)	-26.507*	-49.120***
Log(TEMP)	-50.893***	-50.893**
Δ Log(TEMP)	-64.102***	-201.470***
Log(PREC)	-25.480	-25.797
Δ Log(PREC)	-57.980***	-59.189***

***, **, and * denote significance levels at 1%, 5%, and 10%, respectively.

The first step in the ARDL model estimation is determining the optimal lag lengths for the variables. In this context, the Akaike Information Criterion (AIC) was used to select the most appropriate lag lengths. The results of the lag length selection test are presented in Figure 1.

The AIC criterion evaluated 20 alternative models, and the model with the lowest AIC value, which also exhibited no autocorrelation issues, was selected as the optimal specification. Based on the test results, the most suitable ARDL model structure was determined as (4,1,2).

Figure 1. Lag Lengths



To determine the cointegration relationship between the variables, the F Bound Test was applied, and the results are presented in Table 4. Analyzing the results, the F-statistic value (5.2603) exceeds the critical values for both I(0) and I(1) bounds at all significance levels.

This confirms the existence of a long-term cointegration relationship among the variables. Therefore, it can be concluded that forage crop yield is significantly related to annual average precipitation and annual average temperature in the long run.

Table 4. F Bound Test

Statistic	Value	p-value	I(0)	I(1)
F statistic	5,2603	10%	2,63	3,35
K	2	5%	3,10	3,87
		2.5%	3,55	4,38
		1%		

In Table 5, the long-term coefficient estimates indicate that the effects of the independent variables on the dependent variable are statistically significant.

Examining the signs of the coefficients, it is observed that the annual average temperature has a positive coefficient, while the annual average precipitation has a negative coefficient. This suggests that, in the long run, an increase in temperature is expected to enhance forage crop yield, whereas a decrease in precipitation negatively impacts yield in Erzurum province.

Table 5. Long-Term Coefficient Estimation Results

Variable	**Coefficient**	**Standard Error**	**t-statistic**	**p-value**
LTEMP	1.271	0.446	2.847	0.0137
LPREC	-4.380	1.803	-2.429	0.0304
C	1.023	3.308	3.093	0.0086

To examine both the cointegration relationship and the correction of short-term disequilibria in the long run, an error correction model (ECM) was estimated, and the results are presented in Table 6.

Table 6. Error Correction Model (ECM) Results

Variable	**Coefficient**	**Standard Error**	**t-statistic**	**p-value**
D(LFCY(-1))	0.333	0.136	2.449	0.0293
D(LFCY(-2))	0.019	0.120	0.155	0.8791
D(LFCY(-3))	0.502	0.116	4.318	0.0008
D(LTEMP1)	0.315	0.136	2.314	0.0377
D(LPREC)	-3.040	0.988	-3.077	0.0088
D(LPREC(-1))	-3.018	1.095	-2.756	0.0163
CointEq(-1)*	-0.636	0.125	-5.089	0.0002

Analyzing the functionality of the error correction term (CointEq(-1)), it is found to be statistically significant at the 1% level, negative, and with an absolute value less than 1 (CointEq(-1) = -0.636495, Sig. < 0.01).

This indicates that approximately 64% of any deviation from the long-term equilibrium in forage crop yield is corrected in the following period. Hence, the system exhibits a stable adjustment process, gradually restoring equilibrium over time.

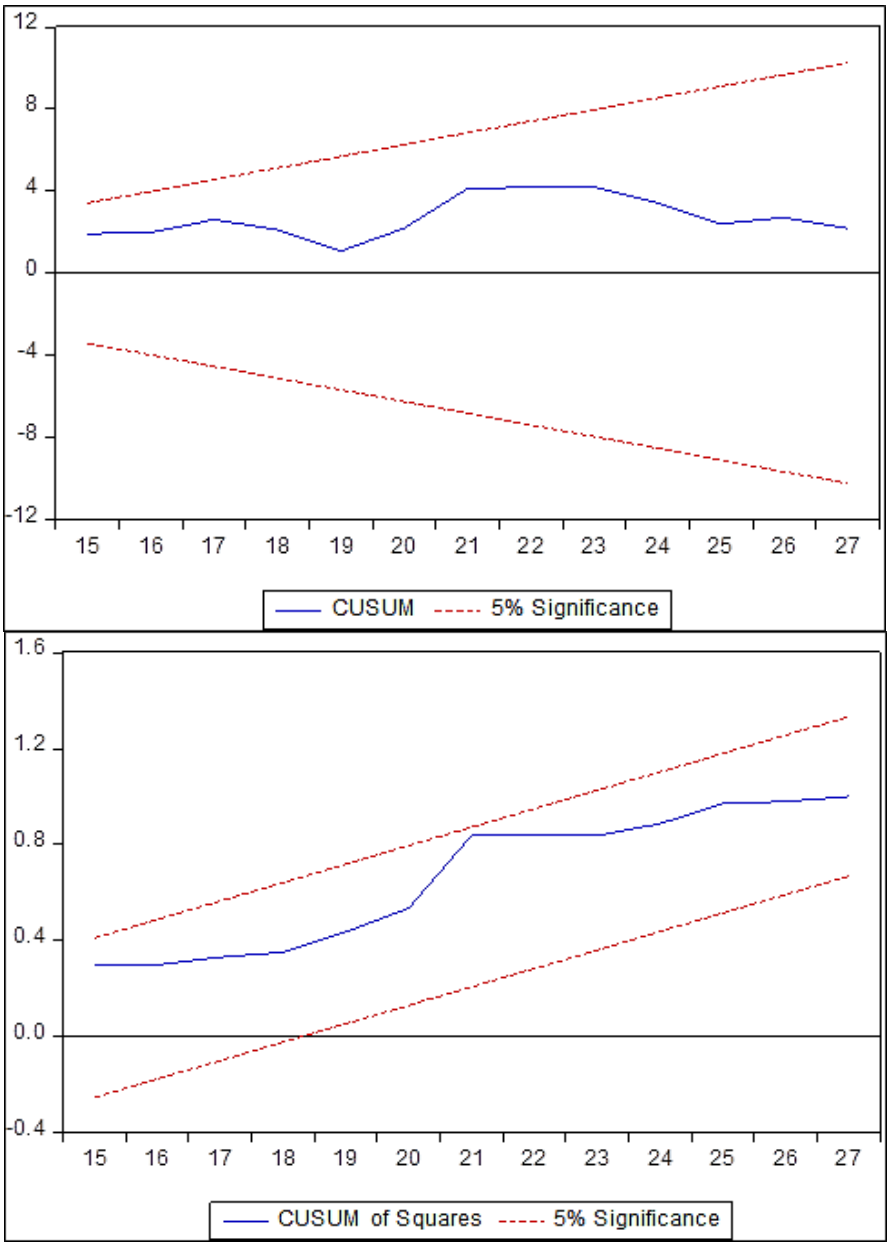
Table 7 presents the diagnostic test results. The diagnostic tests assess whether the model contains specification errors by evaluating normality, heteroscedasticity, and serial correlation. The obtained results indicate that the assumptions of normality and homoscedasticity are satisfied, and no serial correlation is detected. Additionally, since the Ramsey RESET test p-value is 0.8029, it confirms that the model does not suffer from specification errors.

Table 7. Diagnostic Test Statistics

Diagnostic Test	Value	p-value
Jarque-Bera test	1.407764	0.4947
Breusch-Godfrey LM test	0.617896	0.5568
Breusch-Pagan-Godfrey test	0.270569	0.9720
Ramsey Reset	1.039677	0.9341

Figure 2 presents the CUSUM and CUSUMQ graphs. An examination of the graphs indicates that the residuals remain within the confidence bands at the 5% significance level, confirming the stability of the model. Thus, the model is found to be structurally stable over the long term, with no evidence of structural breaks.

Figure 2. CUSUM and CUSUMQ Graphs



Discussion

In this study, the long- and short-term effects of climate change on forage crop yield in Erzurum province were analyzed using the ARDL bounds testing approach. The findings indicate that an increase in annual average temperature may enhance forage crop yield, whereas a decrease in precipitation levels negatively affects

productivity. These results are consistent with the existing literature and are crucial for understanding the economic impacts of climate change on the agricultural sector.

Climate change has significant economic implications for agricultural production and food security. In particular, changes in temperature and precipitation patterns directly influence agricultural productivity, leading to fluctuations in production (Nelson et al., 2010). Declines in agricultural yields can contribute to rising food prices, thereby exacerbating inflationary pressures (Gornall et al., 2010). For instance, a study conducted in the United Kingdom revealed that extreme weather conditions and subsidy cuts in 2023 resulted in a significant decline in farm incomes (The Guardian, 2024). Similarly, a six-year drought in Morocco caused substantial livestock losses, prompting official recommendations to refrain from slaughtering sheep during Eid al-Adha (The Guardian, 2025).

The livestock sector is also directly affected by climate change. A decline in forage crop production increases feeding costs, leading to reduced meat, milk, and egg production (Lobell and Burke, 2010). Rising temperatures disrupt animal feeding patterns and metabolic processes, adversely impacting productivity (Howden et al., 2007). For instance, research on the Turkish agricultural and livestock sector has demonstrated that heat stress negatively affects animal health and reproductive performance (Türkiye Klinikleri, 2022). This situation reduces the supply of animal-based food products, driving up prices and decreasing consumer welfare (Gümüş and Bilgin, 2018).

The Turkish agricultural sector is highly vulnerable to climate change. Studies indicate that the impact of climate change on agricultural production is particularly severe in developing countries (Nelson et al., 2010). The decline in agricultural value-added in Türkiye not only threatens food security but also results in job losses in the agricultural sector (Gümüş and Bilgin, 2018). The income loss in the agricultural sector further reduces the economic welfare of rural populations, exacerbating socioeconomic inequalities (Gornall et al., 2010).

In arid and semi-arid regions, identifying and promoting the cultivation of drought-tolerant alternative forage crops such as pearl millet (Pennisetum glaucum) and Sudangrass (Sorghum sudanense) is of critical importance for ensuring feed security and maintaining livestock productivity under climate stress conditions.

These species are known for their high adaptability to limited water availability, strong root systems, and efficient water use. Their cultivation not only helps stabilize forage yield during drought periods but also supports sustainable livestock farming in regions vulnerable to climate change. Expanding the use of such species in forage crop systems can significantly enhance the resilience of agricultural production in dryland ecosystems (Republic of Türkiye Ministry of Agriculture and Forestry, 2022).

Additionally, adopting low-carbon agricultural practices and strengthening agricultural insurance mechanisms can facilitate risk management for producers, enhancing the sector's resilience (Gornall et al., 2010). The findings of this study are largely consistent with previous research conducted in different regions of Türkiye on the agricultural impacts of climate change. For instance, Akcan et al. (2022) found that rising temperatures negatively affect agricultural production, while increases in humidity and precipitation support yield levels. Similarly, the present study shows that a decrease in annual precipitation leads to reduced forage crop yield in Erzurum province.

In a regional study conducted in Ardahan, Eştürk and Mert (2022) reported that precipitation had a statistically significant short-term effect on forage yield, while temperature did not yield significant results. However, our study reveals a long-term positive effect of temperature on forage crop yield in Erzurum. This divergence may be attributed to agroecological differences between the two provinces and the region-specific temperature thresholds that influence crop responses.

Demirtaş et al. (2021), in a study focusing on the Eastern Anatolia Region, emphasized the role of climatic variables in forage crop production and underlined the importance of irrigation infrastructure and soil structure in mediating these effects. The results obtained from Erzurum are in line with the broader regional patterns; however, the unique contribution of this study lies in its analysis of the temporal dynamics—capturing both short- and long-term effects.

Moreover, Gürbüz and Kadıoğlu (2023) showed that not only climatic factors but also structural elements such as greenhouse gas emissions and agricultural policies significantly influence production decisions. In this context, the findings of the present study support the argument that climatic variability alone does not determine productivity, but that adaptive capacity, policy support, and production infrastructure play critical roles in shaping agricultural outcomes.

CONCLUSION

This study examines the short- and long-term effects of climate change on forage crop yield in Erzurum province using the ARDL bounds testing approach. Results show that while increasing annual temperatures may improve forage yield, declining precipitation negatively affects productivity. The long-term cointegration analysis

confirms a significant relationship between climate variables and forage crop yield, and the error correction model indicates that short-term imbalances are corrected over time, suggesting long-run equilibrium.

These findings highlight the economic risks climate change poses to agriculture and underscore the need for sustainable regional and national policies. Although higher temperatures may increase yields up to a point, reduced precipitation threatens water resources and agricultural sustainability. To build resilience, it is crucial to promote drought- and heat-tolerant forage crops, adopt modern and water-efficient irrigation systems, and implement soil and water conservation practices.

In addition, climate-aligned agricultural support policies are essential. Enhancing subsidies for forage producers, expanding agricultural insurance, and encouraging climate-friendly farming practices will strengthen sectoral sustainability. Farmer training programs should also be scaled up to support informed adaptation decisions and reduce climate-related losses.

In conclusion, forage crop production in Erzurum must be addressed not only as an agricultural issue but also as a matter of economic sustainability and food security. Establishing a climate-resilient agricultural model will ensure long-term productivity, benefit the livestock sector, and contribute to regional development.

While this study sheds light on the effects of climate change on forage crop yield, it also points to valuable future research directions. Comparative studies across Türkiye's diverse agro-climatic regions would help reveal spatial differences. Future research should also consider additional variables such as humidity and extreme weather events. Moreover, expanding crop-specific analyses and integrating socio-economic factors—including farmer adaptation and agricultural policy—could support more robust and policy-relevant conclusions.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

***Tuba KARABACAK* : D**ata curation; formal analysis; investigation; methodology; software; writing— original draft; writing—review and editing.

***Melih OKCU* :** Conceptualization; writing— original draft; writing—review and editing.

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Responses of Some Bread Wheat (*Triticum aestivum* L.) Cultivars to Salinity Stress During Germination and Early Seedling Development Stages

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ABSTRACT

This study aimed to assess the NaCl tolerance of 10 bread wheat (*Triticum aestivum* L.) cultivars during germination and early seedling development. The evaluation was conducted on shoot dry weight and shoot length across five salt concentrations (0, 4, 8, 12, and 16 dS m^{-1}).The effects of salt treatment, variety, and the interaction between salt and variety were statistically significant ($P<0.01$, $P<0.05$) for all examined wheat varieties (Serince, Hamza, NKÜ Lider, Almeria, Adana99, Bora, Eksperia, Falado, Selimiye, Gelibolu). Regression analysis and GGE biplot analysis were conducted to assess varieties under various salt treatments, treating the salt treatments as "environments." The GGE biplot accounted for 97% of the overall variation. The relative positions of variety in the regression graphs and GGE biplot graphs were congruent. The varieties NKÜ Lider, Serince, Bora, and Almeria had a lesser reduce in weight under salt stress compared to the control and demonstrated positive PC1 and PC2 values, thus being recognized as the most salt-tolerant. Conversely, the cultivars Adana99, Selimiye, and Gelibolu, which exhibited low shoot dry weight under control conditions and were significantly impacted by salt treatments, were identified as the most salt-sensitive. The GGE biplot approach determined 8 dS m^{-1} as the threshold for salt tolerance based on the average axis utilized for variety selection. The paper indicates that integrating regression analysis with GGE biplot analysis in future investigations of salt-tolerant genotypes will enhance selection efficacy for researchers.

Key words: Bread wheat, Salinity stress, Germination, Seedling Development

Bazı Ekmeklik Buğday (*Triticum aestivum* L.) Çeşitlerinin Çimlenme ve Erken Fide Gelişim Aşamalarında Tuzluluk Stresine Tepkileri

ÖZ

Bu çalışma 5 adeti 2014 ve öncesi, 5 adeti ise 2014 yılından sonra tescil edilen 10 adet ekmeklik buğday (*Triticum aestivum L.)* çeşidinin çimlenme ve erken fide döneminde 5 tuz konsantrasyonunda (0, 4, 8, 12,16 dS m^{-1}) tuzluluğa toleranslarını sürgün kuru ağırlığı ve sürgün uzunluğu üzerinden değerlendirmek amacıyla yürütülmüştür. Araştırılan bütün ekmeklik buğday çeşitlerinde (Serince, Hamza, NKÜ Lider, Almeria, Adana99, Bora, Eksperia, Falado, Selimiye, Gelibolu) tuz uygulaması, çeşit, tuz x çeşit interaksiyonu istatiksel olarak önemli olmuştur ($P<0.01$, $P<0.05$). Farklı tuz uygulamalarında çeşitleri değerlendirmek amacıyla regresyon analizi ve GGE biplot analizi (tuz uygulamaları = çevre) yapılmıştır. GGE biplot analizi toplam varyasyonun %97'sini açıklamıştır. Her çeşide ait oluşturulan regresyon grafikleri ile GGE biplot grafiklerinde çeşitlerin konumları birbirleri ile uyumlu olmuştur. Kontrol uygulamasında yüksek ağırlığa sahip olan tuz uygulamalarına göre ağırlığı daha az değişen NKÜ Lider, Serince, Bora ve Almeria çeşitleri pozitif PC1 ve PC2 değerleri ile tuzluluğa en dayanıklı çeşitler olarak belirlenmiştir. Kontrol uygulamasında yüksek kuru sürgün ağırlığı ve sürgün uzunluğuna sahip olan ancak, tuz uygulamaları ile ağırlık azalma oranı en fazla olan Adana99, Gelibolu ve Selimiye çeşitlere ait PC2 değerleri de düşük

gerçekleşmiştir. Kontrol uygulamasında düşük ağırlığa salip olan ve tuz uygulamalarında yüksek oranda olumsuz olarak etkilenen Adana99, Selimiye ve Gelibolu çeşitleri tuzluluğa en hassas çeşitler olarak belirlenmiştir. GGE biplot yönteminde çeşit seleksiyonu için kullanılan ortalama eksene göre tuzluluk eşik değeri 8 dS m^{-1} olarak belirlenmiştir. Tuzluluğa dayanıklı genotipleri belirlemek amacıyla yürütülecek araştırmalarda, regresyon analizi ile GGE biplot analizinin birlikte kullanılması araştırıcıları daha başarılı seleksiyon yapmasını sağlayacaktır.

Anahtar Kelimeler: Ekmeklik buğday, Tuzluluk stresi, Çimlenme, Fide Gelişimi

INTRODUCTION

The swift escalation of the global population and climate change resulting from unsustainable human practices have exerted considerable strain on agricultural output. The agricultural industry is acutely affected by climatic changes, especially abiotic stressors like salt, which adversely influence crop output. FAO statistics indicate that the global population is projected to attain 9.3 billion by 2050, requiring a 35% to 56% rise in food demand. Climate change is anticipated to increase overall food demand by as much as 62%, increasing worries over global food security (Van Dijk et al., 2021). The prevalence of undernourishment is increasing, with almost 768 million individuals (9.9% of the global population) currently experiencing hunger (Marson et al., 2023).

Natural water sources generally contain dissolved minerals and ions, with concentrations varying based on ambient circumstances. Climate change and global warming are modifying the hydrological cycle, impacting both the volume and physicochemical characteristics of water resources. Global warming elevates atmospheric evaporation rates, diminishing total water supplies and augmenting the mineral concentration of the remaining water.

Drought, along with heightened evaporation, intensifies salt deposition on the soil surface, resulting in osmotic stress in plant cells. Salinity stress adversely impacts photosynthetic rates, cellular metabolism, and overall plant growth, leading to diminished agricultural yields.

Abiotic environmental pressures are a primary factor in the reduction of yield in global agricultural output. Studies demonstrate that these stressors diminish the average yield of numerous basic crops by over 50% globally (Koyro et al., 2008). Drought is regarded as the primary stressor, posing a substantial danger to agricultural output (Liang, 2016). Salinity, the second most significant environmental stressor, severely limits agricultural performance and productivity (Wang et al., 2003; Li et al., 2020). Salinity stress adversely impacts agricultural ecosystems, resulting in diminished productivity and decreased biodiversity (Ashraf & Foolad, 2007). The negative impact of salinity on plants is exacerbated in dry and semi-arid settings. Environmental stressors are most pronounced during germination, seedling development, and early growth phases (Demir et al., 2003). Kanber and Ünlü (2010) reported that high salt concentrations significantly inhibit water absorption in the root zone, while deterioration of the soil structure worsens water uptake by plants and prevents water transport to the roots.

About one-third of agricultural land is affected by salt issues, with estimates varying from 400 to 950 million hectares (Hasegawa et al., 1986; Özkaldı et al., 2004; Taghipour & Salehi, 2008). Each year, approximately 10 million hectares of agricultural land are rendered unproductive because of salt accumulation. In Türkiye, approximately 1.5 million hectares of agricultural land are affected by salinity (TÜİK, 2004). Salinity's impact on plant development differs between species. Cereals, especially during germination and early seedling phases, exhibit significant sensitivity to increased salinity (Ghoulam & Fares, 2001). With increasing salinity stress, germination rates diminish, plant height drops, and both leaf area and tiller numbers are reduced (Gupta & Srivastava, 1989; Pessarakli et al., 1991). Begum et al. (1992) indicated that NaCl stress diminishes germination rates in wheat, but Vardar et al. (2014) noted considerable reductions in root length, shoot height, and germination vigor with escalating salt concentrations. Benlioğlu et al. (2015) also recorded detrimental alterations in the growth and development metrics of plants subjected to salt stress.

Wheat is the most extensively cultivated and consumed cereal worldwide, including in Turkey. Data from 2021-2022 indicates that per capita wheat consumption in Turkey rose by 7.4% to 179.5 kg, while food-grade wheat utilization increased by 8.9% to 15.18 million tons (TÜİK, 2022). Ensuring the sustainability of wheat production necessitates the creation of cultivars resistant to biotic and abiotic challenges, alongside the application of suitable farming techniques. Plants react to stress circumstances via resistance, tolerance, and adaptability mechanisms (Mooney & Hobbs, 1986; Pagán & García-Arenal, 2018). To attain agricultural sustainability, it is imperative to develop cultivars that maintain soil health, optimize water resource usage, and endure climatic change. Bread wheat (*Triticum aestivum* L.) is a crucial crop extensively grown in different countries and functions as a primary food source globally (Shewry, 2009). Nonetheless, wheat productivity is negatively impacted by numerous abiotic stressors. Salinity stress specifically impairs physiological and biochemical processes, hence restricting growth and development (Wang et al., 2003). Studies indicate that wheat yields diminish by roughly 7% when salt

concentrations surpass 6 dS/m (Shannon, 1998). Extended exposure to salinity inflicts irreparable harm on plant physiology, rendering yield loss unavoidable (Munns & Tester 2008).

Consequently, thorough investigations into the salt tolerance mechanisms of wheat cultivars will facilitate the creation of high-yield, salt-resistant variants via modern breeding methodologies. This research enhances sustainable wheat production and is crucial for bolstering global food security. Regression analysis is employed to ascertain the salt tolerance levels of genotypes in several plant species (Kandil et al., 2012; Güldüren & Elkoca, 2012; Nasüaku et al., 2013; Lavrenko et al., 2019). GGE biplot analysis is a graphical technique for elucidating trial outcomes across diverse habitats, assisting researchers in determining the optimal genotypes for particular situations and identifying the most suitable environments for selection (Akçura et al., 2019).

In the research, the effects of five different Electrical Conductivity (ECi) levels [Control (0), 4, 8, 12 and 16 dS m^{-1}] prepared with NaCl salt on shoot dry weights and lengths of 10 bread wheat varieties were investigated. Stress tolerance index (STI) values were used to evaluate the variety tolerance levels using regression analysis and GGE biplot methodologies.

MATERIALS AND METHODS

This experiment aimed to assess the impact of salinity stress, induced by varying NaCl concentrations, on the germination and initial seedling growth of bread wheat cultivars commonly cultivated in Turkey, namely in the Çanakkale, Marmara, and Thrace regions. Bread wheat varieties used in the research and the organizations they are registered with are shown in Table 1.

Table 1. Information of the cultivars used in the study

No	Cultivar Name	Registering Institution	Registration Year
1	Serince	GAP Agricultural Research Institute	2021
2	Hamza	Tekcan Seed Company	2015
3	NKÜ Lider	NKÜ Faculty of Agriculture	2016
4	Almeria	Alfa Seed Company	2019
5	Adana99	Eastern Mediterranean Agricultural Research Institute	1999
6	Bora	Tasaco Agriculture	2014
7	Falado	Syngenta Agriculture	2021
8	Esperia	Tasaco Agriculture	2011
9	Selimiye	Trakya Agricultural Research Institute	2009
10	Gelibolu	Trakya Agricultural Research Institute	2005

The experiment was carried out in the 2024-2025 growing season at the İçdaş Agriculture, Seed, and Technology Laboratory. The research utilized a split-plot design with three replications, wherein cultivars constituted the main plots and five NaCl solutions (0, 4, 8, 12, and 16 dS m^{-1}) served as the sub-plots. Sterilized distilled water was utilized to formulate salt solutions to mitigate the influence of extraneous chemical variables. Seeds were surface sterilized using a 2% sodium hypochlorite solution, then rinsed three times with sterilized distilled water. Sterilized seeds were positioned in 9 cm diameter petri dishes containing 10 ml of saline solution, with 20 seeds per dish, interleaved between sterilized germination papers. To inhibit evaporation, petri plates were encased in cling film and positioned within sealed transparent plastic bags. The dishes were subsequently positioned in a climate-controlled laboratory with a 16-hour light and 8-hour dark cycle at 25 ±1°C for 8 days for germination (ISTA, 1996) and 14 days for initial seedling development. Seeds were considered germinated when radicles attained a length of 2 mm (Adjel et al., 2013). Germination papers and saline solutions were substituted bi-daily throughout the experiment.

Shoot dry weight and shoot length were employed to assess cultivar tolerance levels. The maximum dosage (16 dS m^{-1}) was omitted from assessment due to inadequate data. STI values were computed for each concentration according to the methodology outlined by Rasheed et al. (2015). Data were examined by individual variance analyses for each concentration, a combined variance analysis for cultivar × salt concentration interactions, regression analysis, and GGE biplot analysis.

Biplot analysis relies on the graphical depiction of matrices derived from principal component analysis (Gabriel, 1971), with axes designated as PC1 and PC2.This study utilized GGE biplot analysis to determine that cultivars with PC1 > 0.0 exhibited greater shoot dry weights and lengths in saline conditions, whereas PC1 < 0.0 signified sensitivity to salinity. PC2 values approaching 0.0 showed stability under saline treatments, while elevated PC2 values signified instability. Vector lengths and placements of salt concentrations in relation to the average salt concentration were utilized for cultivar selection and the establishment of crucial salt tolerance thresholds. Variance analyses were executed utilizing SAS JMP (SAS Institute, 2004), and biplot analyses were carried out employing GGE-biplot (Yan, 2014).

RESULTS AND DISCUSSION

The shoot dry weights and lengths of the cultivars were strongly influenced by the salt levels applied. An increase in salt content (from 0 dS m^{-1} to 12 dS m^{-1}) resulted in a significant decrease in shoot dry weights and lengths.

The shoot dry weight mean of the control group was measured 12.27 g. The cultivars with the highest shoot dry weights were Bora (11.93 g), NKÜ Lider (10.90 g), and Falado (10.77 g). The lowest shoot dry weight was recorded in Adana99 (6.43 g), succeeded by Selimiye (6.87 g), Gelibolu (7.77 g), and Esperia (8.37 g).

In terms of shoot lengths, the control group exhibited the greatest value from the Hamza cultivar, measuring 19.65 cm. The subsequent records were Serince (17.32 cm), Bora (17.21 cm), and Falado (16.02 cm), with Almeria recording the lowest result at 13.50 cm.

At a salt concentration of 4 dS m^{-1}, the mean shoot dry weight was 8.90 g. The greatest weight in this therapy was recorded for Bora (11.87 g), followed by Serince (11.32 g). Adana99 exhibited the lowest weight, followed by Selimiye and Gelibolu (6.89–6.56 g).

Regarding shoot lengths at this concentration, the average length was 14.43 cm, with Serince, Hamza, and NKÜ Lider showing the highest values (16.01–16.05–15.53 cm). The remaining seven cultivars fell below the average, with Esperia exhibiting the shortest shoot length at 13.12 cm.

At 8 dS m^{-1}, the mean shoot dry weight was 7.26 g.The maximum value was recorded from Bora, succeeded by Falado (8.68 g) and Serince (8.60 g). Conversely, Adana99 demonstrated the lowest shoot dry weight at 3.60 g, significantly lower than all other entries. The mean shoot length at this salinity was 11.95 cm, with Hamza exhibiting the maximum value of 13.38 cm and Gelibolu the minimum at 10.70 cm.

At 12 dS m^{-1}, the highest shoot dry weight was recorded in Falado (4.32 g), succeeded by Serince (4.12 g) and Bora (4.01 g). The minimum value was documented for Selimiye (2.66 g). The mean shoot length at this salinity was 4.32 cm, with NKÜ Lider exhibiting the greatest measurement, succeeded by Falado at 4.92 cm and Bora at 4.91 cm.

The Stress Tolerance Index (STI) is a frequently utilized measure for identifying stress-tolerant cultivars. STI measures reductions in shoot dry weight and shoot length under stress conditions relative to the control group, with cultivars exhibiting higher STI values being tolerant (Akçura et al., 2011; Rasheed et al., 2015).

A notable decline was noted in all varieties when salinity rose from 4 dS m^{-1} to 12 dS m^{-1}. In terms of shoot dry weight data, at a saline level of 4 dS m^{-1}, the cultivars NKÜ Lider, Bora, and Selimiye demonstrated superior values relative to the control group (1.047–1.041–1.042). The Gelibolu cultivar had the lowest shoot dry weight value (0.608 g) within the same salinity group. At salt levels below 8 dS m^{-1}, the greatest STI value was recorded for Selimiye (0.958), followed by Esperia (0.885) and Almeria (0.861). The minimum values were documented in Adana99 (0.537) and Gelibolu (0.552). At 12 dS m^{-1} salinity, the highest value was observed in Adana99 (0.429), while the lowest was in Gelibolu (0.265). The mean STI value for all kinds was 0.929 at 4 dS m^{-1}, declining to 0.767 and 0.366 at elevated salinity levels of 8 and 12 dS m^{-1}, respectively. In comparison to the 4 dS m^{-1} treatment, STI levels decreased by 17.4% at 8 dS m^{-1} and by 60.6% at 12 dS m^{-1}. The analysis of the table indicated that, in comparison to the control group, the Adana99 variety exhibited the most significant reduction (38%) under 4 dS m^{-1} salinity. At a salinity of 8 dS m^{-1}, the Esperia variety demonstrated the most substantial loss (59%), but at 12 dS m^{-1} salinity, the Bora variety exhibited the largest reduction (67%).

Table 2. Stress tolerance indices of shoot dry weight and shoot length of cultivars according to applied salinity

Cultivars	Shoot Length (cm)				Shoot Dry Weight (mg)				Shoot Length (cm)			Shoot Dry Weight (mg)		
	Salt Concentrations(dS m^{-1})				Salt Concentrations(dS m^{-1})				Stress Tolerance Index			Stress Tolerance Index		
	0	4	8	12	0	4	8	12	4	8	12	4	8	12
Serince	17.32	16.01	12.69	4.35	12.27	10.5	8.6	4.07	0.936	0.742	0.254	0.929	0.761	0.36
Hamza	19.65	16.05	13.38	2.82	9.9	9.65	8.32	3.85	0.825	0.688	0.145	0.924	0.79	0.368
NKÜ Lider	15.36	15.53	13.35	6.08	10.9	11.1	8.2	3.98	1.037	0.891	0.406	1.047	0.774	0.374
Almeria	13.5	13.81	10.72	4.12	8.7	8.12	7.23	2.98	1.013	0.781	0.309	0.968	0.861	0.354
Adana99	14.93	13.76	11.57	3.55	6.43	5.78	3.6	2.85	0.933	0.784	0.241	0.861	0.537	0.429
Bora	17.21	14.83	12.49	4.91	11.93	11.87	8.85	4.01	0.822	0.692	0.272	1.041	0.781	0.348
Falado	16.02	14.85	12.07	4.92	10.77	10.1	8.68	4.32	0.887	0.721	0.294	0.902	0.774	0.387
Esperia	14.01	13.12	11.57	4.06	8.37	7.56	6.87	2.78	0.941	0.83	0.291	0.97	0.885	0.359
Selimiye	13.67	13.21	10.96	4.44	6.87	6.56	6.02	2.66	0.963	0.799	0.324	1.042	0.958	0.418
Gelibolu	14.5	13.13	10.7	3.92	7.77	6.89	6.24	3.01	0.768	0.626	0.229	0.608	0.552	0.265
Avg.	15.62	14.43	11.95	2.82	9.39	8.81	7.26	3.45						
Min.	13.5	13.12	10.7	3.92	6.43	5.78	3.6	2.66						
Max.	19.65	16.05	13.38	6.08	12.27	11.87	8.85	4.32						
Genotype	**	*	**	**	**	**	**	*						
CV	6.19	7.54	9.53	18,24	5.84	8.64	10.91	15.99						
R2	0.85	0.8	0.65	0.61	0.85	0.8	0.65	0.54						

**: P< 0.01, LSD: Least Significant Difference, CV: Coefficient of Variation, R2: Coefficient of Regression

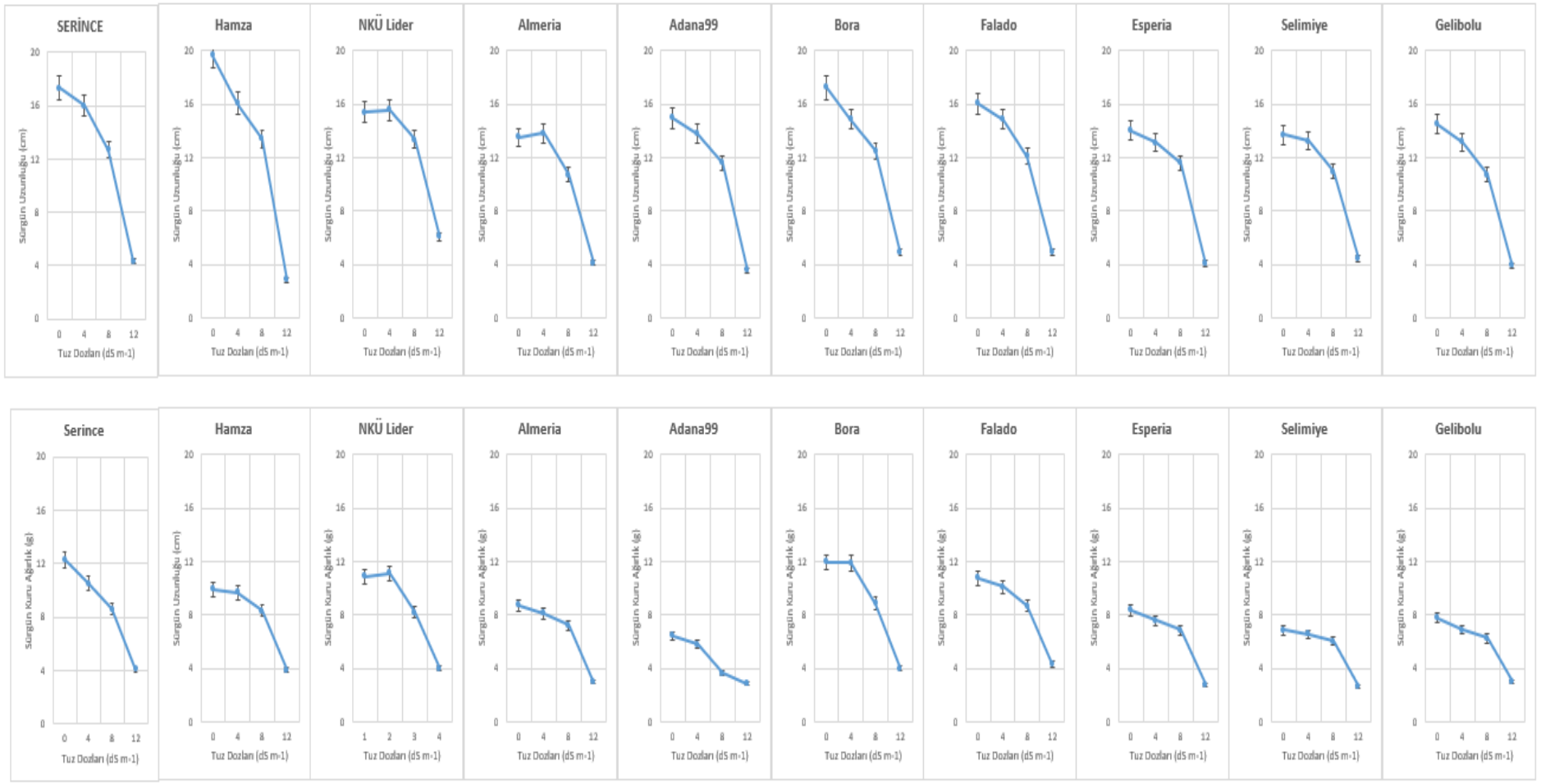

Figure 1. Variations in shoot dry weight and shoot length according to the salt concentrations applied to the varieties

In terms of shoot length, the NKÜ Lider variety exhibited the highest STI value under the 4 dS m^{-1} salt treatment compared to the control group, whereas the Gelibolu variety recorded the lowest value (0.768). In the 8 dS m^{-1} treatment, NKÜ Lider exhibited the highest result at 0.891, followed by Esperia at 0.830. The Gelibolu variety again recorded the lowest rating at 0.626. In the 12 dS m^{-1} salt treatment, NKÜ Lider exhibited the highest value at 0.406, whilst the Hamza variety recorded the lowest value at 0.145.

The 4 dS m^{-1} salt treatment resulted in an average shoot length STI value of 0.913 across all types. For other salt treatments, the results were 0.756 and 0.277, respectively. The 4 dS m^{-1} salt treatment resulted in a 0.913 value, while the 8 dS m^{-1} treatment decreased it by 17.2%. This value decreased by 70% after the 12 dS m^{-1} treatment.

The Almeria variety experienced the biggest percentage loss (23% compared to the control group) under the 4 dS m^{-1} salt treatment. The Hamza variety showed the largest decline (79%) under the 8 dS m^{-1} treatment. Similarly, the 12 dS m^{-1} salt treatment resulted in a 67% decrease.

As with all of these findings, similar experiments undertaken by various researchers have revealed that differences in germination rates are critical in determining salinity tolerance (Saxena et al., 1994). For these reasons, seed germination in petri dishes under saline conditions is commonly employed to quickly assess salt tolerance (Jana and Slinkard, 1976). Many researchers have used petri dishes containing different salt solutions to test salt tolerance in various plant species (beans, sorghum, bread wheat, vegetables) (Goertz and Coons, 1989; Elkoca, 1997; Esechie, 1994; Kırtok et al., 1994; Cucci et al., 1994), and resistant species and varieties were identified in a short time.

The adaptability of plants to specific adverse situations differs based on their growth phases; nonetheless, possessing a robust seedling structure is crucial (Akram et al., 2010). Expeditious and uniform seed germination throughout germination phases, together with swift development in the initial seedling stages, are crucial for plant cultivation in salty soils (Foolad, 2004; Ashraf et al., 2008). In the cultivation of bread wheat, the germination and initial seedling development stages are identified as the periods during which plants exhibit heightened sensitivity to unfavorable environments (Ashraf and Lin, 1994). The GGE biplot approach is one of the most effective techniques for visually assessing the responses of cultivars to varying environments. Consequently, GGE biplot analysis was employed to visually assess the tolerance levels of bread wheat cultivars subjected to various salt treatments. The variety exhibiting the greatest shoot weight and shoot length at specific salt concentrations was identified, as well as the variety demonstrating optimal tolerance to particular salt treatments (Akçura, 2021).

The biplot illustrated in Figures 2-3 is utilized to ascertain which variety had the greatest dry shoot weight and shoot length at specific salt concentrations, as well as to identify which variety demonstrated superior tolerance at those concentrations.

Analysis of PC1 axis values indicated a positive correlation between varietal salt tolerance levels and ascending PC1 scores, with the NKÜ Lider, Bora, Selimiye, and Esperia varieties exhibiting the highest shoot dry weights/lengths and maximum PC1 values, whereas varieties with PC2 values near 0.0 displayed enhanced relative tolerance. The GGE biplot enabled visual analysis of inter concentration interactions, with vector angle cosine values (Yan, 2014) statistically illustrating correlations with salt doses, demonstrating a gradual angular expansion from control to 12 dS m^{-1} (minimum angle: 4-8 dS m^{-1}; maximal angle: 12 dS m^{-1}). Biplot analysis of treatment responses (Figures 2-3) revealed that NKÜ Lider, Bora, and Selimiye consistently surpassed mean shoot dry weight values with positive PC1 positioning, while NKÜ Lider, Almeria, Serince, and Esperia excelled in shoot length parameters, all clustering within the biplot's tolerant zone. The graphical analyses (Figures 2-3) elucidated concentration-specific selection efficacy, with the 12 dS m^{-1} treatment demonstrating the highest discriminative power for tolerance screening.

It was noted that an increase in the saline tolerance index (STI) corresponded with a decrease in the dry weights and lengths of the cultivars. Bread wheat varieties demonstrated comparable alterations in shoot dry weight and shoot length under both control and 4 dS m^{-1} conditions. The varieties NKÜ Lider, Almeria, and Bora produced results that were comparable to the control group for both measures. Moreover, at 8 and 12 dS m^{-1} levels, the decreases in dry shoot weight and shoot length were more significant, with the salt-treated groups exhibiting notable reductions relative to the control. The 8 dS m^{-1} salinity level was identified as the most effective electrical conductivity (ECi) level, as demonstrated by data from prior and subsequent salinity levels. This indicates that 8 dS m^{-1} is theoretically near the optimal selection threshold and may improve selection efficiency if utilized as a critical parameter in breeding efforts for bread wheat.

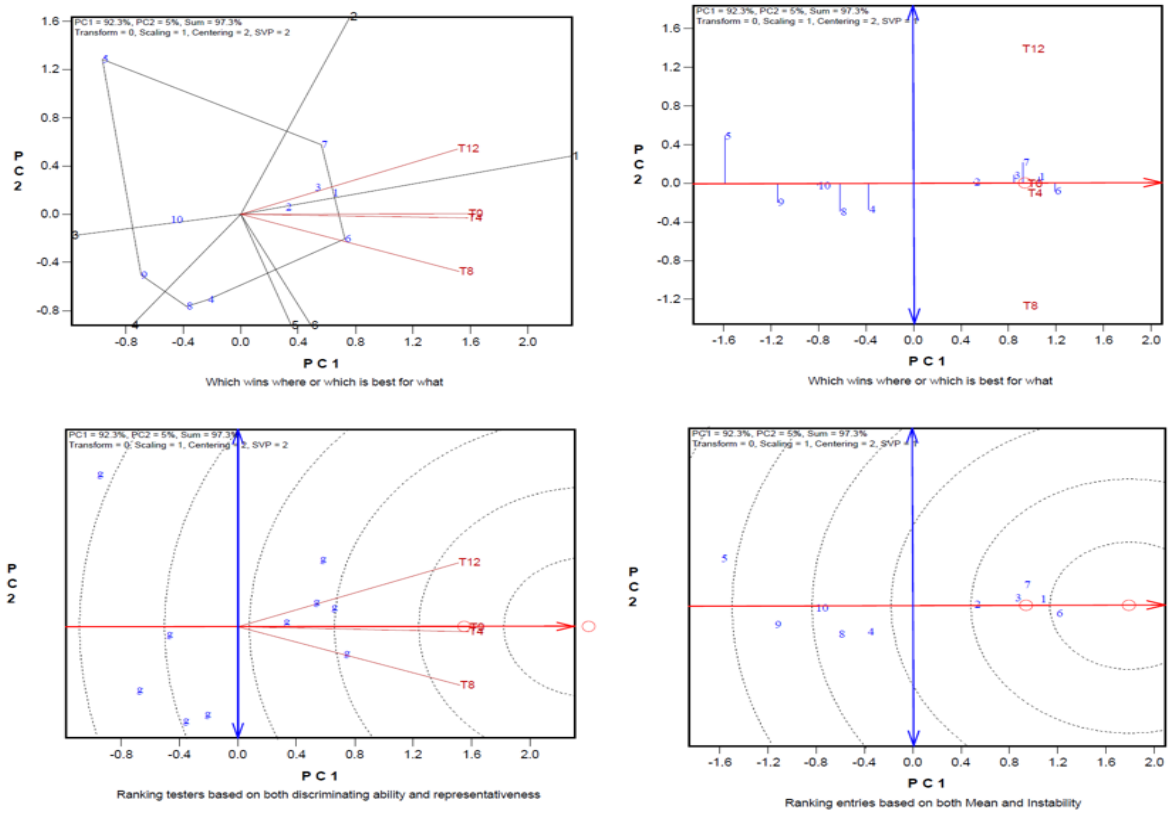

Figure 2. Interaction of genotype and salt concentration on shoot dry weight illustrated by GGE biplot graphics.

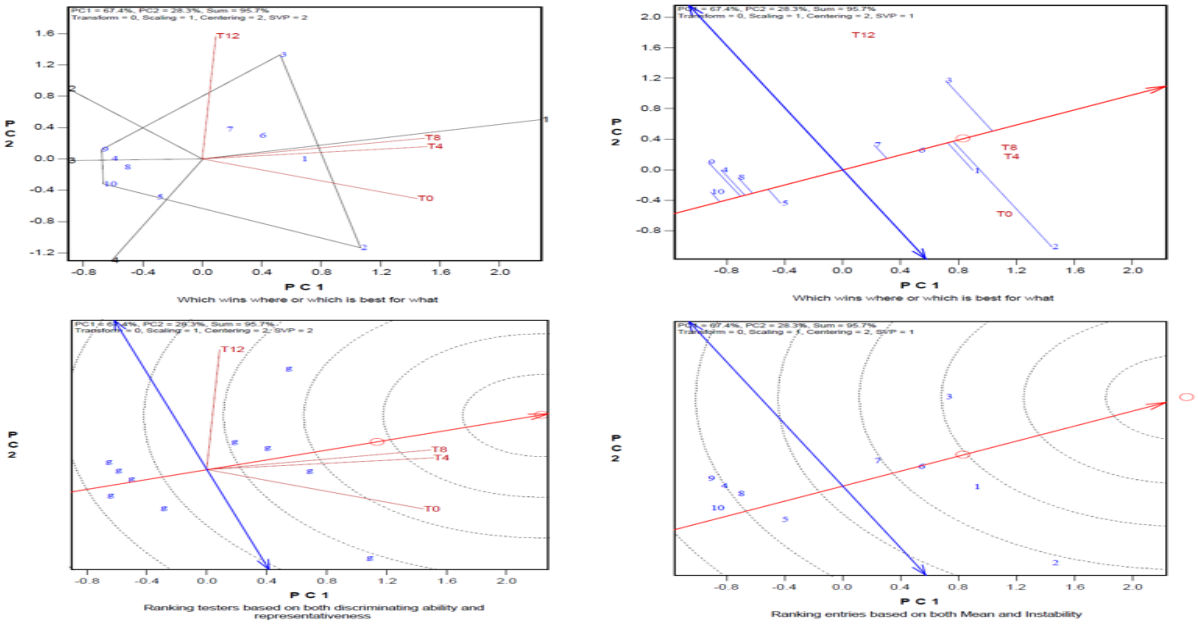

Figure 3. GGE biplot graphics illustrating the interaction between genotype and salt concentration on shoot length

This work utilized the GGE biplot approach, created by plant breeders for analyzing genotype × environment (G×E) interactions in multi-environment yield trials (Yan, 2014), alongside regression analysis, commonly applied to evaluate stress tolerance. Regression graphs and GGE biplots enabled the depiction of varietal responses to various salt treatments (Akçura, 2021).

The regression analysis indicated that varieties with the most significant disparities in maximum and minimum shoot dry weight and shoot length under saline stress conditions (NKÜ Lider, Bora, Serince) displayed low PC2 values in the biplot analysis. The GGE biplot methodology, treating salt concentrations as separate environments, successfully delineated: (1) the superior varieties at specific salinity levels, (2) the most tolerant varieties across all concentrations, (3) the ideal salt concentrations for genotype selection, (4) the interrelationships among varying salt concentrations, and (5) the most salt-sensitive varieties. The analytical methods effectively achieved the main research goal of identifying salt-tolerant cultivars, as the GGE biplot analysis allowed for an in-depth assessment of genotype performance under different salinity levels, offering critical insights for breeding programs focused on creating stress-resistant wheat varieties.

In the GGE biplot analysis, all salt concentrations demonstrated positive PC1 values, however the control and 4 dS m^{-1} treatments revealed negative PC2 values, with the remaining salt treatments exhibiting positive PC2 values. Significantly, at salinity levels of 8 dS m^{-1} and above (except 16 dS m^{-1}, where germination occurred without following shoot and root development in all bread wheat varieties), there were large reductions in shoot dry weight and length, which correlated with substantial fluctuations in PC2 values. A comparative examination indicated little changes in PC1 values among salt concentrations, but PC2 values exhibited significant variance. The data indicate that for salinity-based varietal selection, the PC2 axis is a more effective criterion than the PC1 axis, offering superior discriminative power for selecting salt-tolerant genotypes under diverse stress circumstances.

CONCLUSION

In conclusion, the combined GGE biplot and regression studies definitively indicated NKÜ Lider, Serince, Bora, and Almeria as the most salt-tolerant cultivars, whereas pre-2014 types (Selimiye, Adana99, Gelibolu) shown significant salt sensitivity. The research determined that utilizing 8 dS m^{-1} ECi as a selection criterion effectively selects genotypes exhibiting both extensive adaptability and salt tolerance in bread wheat breeding. Moreover, the integration of regression analysis and GGE biplot approach with traditional variance analysis markedly improves the selection efficiency for genotypes tolerant to abiotic stress, especially in saline environments. This comprehensive analytical method equips breeders with effective tools for enhanced genotype selection in stress breeding initiatives.

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Author Contributions

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Original Article

Isolation and Characterization of *Bacillus* spp. Producing Indole-3-Acetic Acid (IAA) and Solubilizing Inorganic Phosphate from the Rhizosphere of Medicinal Sage (*Salvia officinalis*)

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ABSTRACT

The production of indole-3-acetic acid (IAA) is a key characteristic of plant growth-promoting bacteria (PGPR). This hormone, synthesized by PGPR in the rhizosphere, is responsible for the division, elongation, and differentiation of plant cells and plays a crucial role in various physiological mechanisms in plants. 21 bacterial isolates were obtained from the rhizosphere of medicinal sage (*Salvia officinalis* L.) in this study. This study aimed to characterize the indigenous bacterial community in the rhizosphere of *S. officinalis* and evaluate their potential as microbial fertilizers, focusing on their IAA production and phosphate solubilization capabilities. Among these isolates, 9 were identified as *Bacillus* sp. through morphological and biochemical tests as well as the MALDI-TOF MS method. Furthermore,9 isolates, 5 (BCM-3, BTM-1, BN-5, BCM-4, and BGM-13) demonstrated the ability to dissolve inorganic phosphate, while 6 (BCM-3, BCM-4, BSM-1, BSM-2, BTM-1, and BN-5) produced indole-3-acetic acid (IAA) in varying percentages. IAA production was assessed in nutrient broth (NB) medium supplemented with 0.2% L-tryptophan and measured at different incubation times. The results revealed that maximum IAA production by *Bacillus cereus* BCM-3 and BCM-4 was achieved after 3 days of incubation, with the highest production observed in BCM-3 (129.8 µg ml^{-1}). Furthermore, *B. cereus* BCM-3 and BCM-4 exhibited the highest inorganic phosphate solubilization performance among all tested *Bacillus* isolates. Our findings demonstrated that BCM-3 and BCM-4, isolated from the rhizosphere of medicinal sage, have significant potential for use as microbial fertilizer applications due to their high IAA production and inorganic phosphate solubilization abilities.

Key words: Medicinal sage, *Bacillus* spp., PGPR , microbial fertilizers

Tıbbi Adaçayı (*Salvia officinalis* L.) Rizosferinden İndol-3-Asetik Asit (IAA) Üreten ve İnorganik Fosfatı Çözen Bacillus Türlerinin İzolasyonu ve Karakterizasyonu

ÖZ

İndol-3-asetik asit (IAA) üretimi, bitki büyümesini teşvik eden bakterilerin (PGPR) temel bir özelliğidir. Rizosferde bitki gelişimini teşvik eden rizobakteri (PGPR) tarafından sentezlenen bu hormon, bitki hücrelerinin bölünmesinden, uzamasından ve farklılaşmasından sorumludur ve bitkilerde çeşitli fizyolojik mekanizmalarda önemli bir rol oynar. Bu çalışmada, tıbbi adaçayı (*Salvia officinalis* L.) rizosferinden 21 bakteri izolatı elde edilmiştir. Bu izolatlardan dokuz tanesinin morfolojik, biyokimyasal testler ve MALDI TOF MS yöntemi ile *Bacillus* sp. olduğu belirlenmiştir. Dokuz izolat arasından beş tanesinin (BCM-3, BTM-1, BN-5, BCM-4 ve BGM-13) inorganik fosfat çözdüğü, beş tanesinin (BCM-3, BCM-4, BSM-1, BSM-2, BTM-1 ve BN-5) farklı oranlarda IAA ürettiği belirlenmiştir. IAA üretimi, % 0,2 L-triptofan eklenmiş nutrient broth (NB) ortamında farklı inkübasyon sürelerinde gerçekleşmiştir. Sonuçlar, *Bacillus cereus* BCM-3 ve BCM-4'ün maksimum IAA üretiminin 3 günlük inkübasyon süresinde gerçekleştiğini ortaya koymuştur. En iyi IAA üretimi, 3 günlük inkübasyon süresinde *B. cereus* BCM-3'ten (129.8 µg ml^{-1}) elde edilmiştir. Ayrıca, *B. cereus* BCM-3 ve BCM-4 izolatlarının test edilen tüm Basillus izolatları arasında en iyi inorganik fosfat çözme performansını sergilemiştir. Bulgularımız, tıbbi adaçayı topraklarından izole edilen BCM-3 ve BCM-4 izolatlarının yüksek IAA üretimi ve inorganik fosfat çözme

yetenekleri nedeniyle mikrobiyal gübre uygulamaları için önemli bir potansiyele sahip olduğunu göstermiştir. Bu çalışma, *Salvia officinalis* (adaçayı) rizosferindeki yerel bakteriyel topluluğu karakterize etmeyi, IAA üretme ve inorganik fosfat çözme yetenekleri ile mikrobiyal gübre potansiyellerini değerlendirmeyi amaçlamıştır.

Anahtar kelimeler: Tıbbi adaçayı*, Bacillus* spp., PGPR , mikrobiyal gübre

INTRODUCTION

Auxins are a diverse group of carboxylic acid signaling molecules that regulate various physiological processes in plants. These are synthesized primarily in the aerial parts, such as the shoot apex, auxins are transported to the sub-aerial regions of the plant (Park et al., 2017). Indole-3-acetic acid (IAA), a key auxin, plays a crucial role in plant-microbe interactions and directly enhances plant growth. IAA produced by plant growth-promoting rhizobacteria (PGPR), including Bacillus species, is synthesized through five tryptophan-dependent metabolic pathways: indole-3-acetamide (IAM), indole-3-acetonitrile (IAN), tryptophan side-chain oxidase (TSO), tryptamine (TAM), and indole-3-pyruvate (IPyA) (Lin et al., 2015). Bacterial auxins, particularly indole-3-acetic acid (IAA), promote root growth by supporting the development of lateral roots, thereby increasing root surface area (Kong et al., 2020). This enhanced root architecture improves nutrient uptake, ultimately contributing to better plant growth and yield. Auxins also influence overall plant biology and activate additional mechanisms employed by plant growth-promoting bacteria (PGPB) to support plant growth and development. Members of the genus *Bacillus*, which have the ability to synthesize IAA and solubilize phosphate, constitute an important group of plant growth promoting rhizobacteria (PGPR), which are abundant in the rhizosphere (Etesami and Glick, 2024). Numerous studies have been reported on indigenous IAA-producing *Bacillus* strains (Lim and Kim, 2009; Prashanth and Mathivanan, 2010).

Medicinal plants such as sage have been used for thousands of years to provide nutrients, treat health disorders, and prevent diseases. Sage (*Salvia officinalis* L.-family Lamiacea) is an important medicinal and aromatic plant that grows in various parts of the world is widely used for its essential oils in the food, medicine and perfumery (Sharma et al., 2019). The harmful effects of chemical fertilizers on the environment and human health, coupled with excessive price increases, have necessitated the development of sustainable approaches in the cultivation of medicinal and aromatic plants such as sage. This highlights the importance of eco-friendly alternative fertilizers that can enhance plant growth (Marcelino et al., 2023). Currently, the application of plant growth-promoting rhizobacteria (PGPR), one of the environmentally friendly and sustainable agricultural approaches, holds significant potential for enhancing plant growth and nutrient uptake (Uçar et al., 2023). Anbi et al. (2020) stated that the application of plant growth-promoting rhizobacteria (PGPR) led to significant increases in plant height, leaf area, number of leaves, number of flowering shoots, chlorophyll a, and chlorophyll b contents in *Salvia officinalis*. Yolci et al. (2022) reported that the application of plant growth-promoting rhizobacteria (PGPR), including *Azospirillum lipoferum*, *Bacillus megaterium*, and *Frateuria aurentia*, mitigated the toxic effects of increasing boron doses in medicinal sage. Furthermore, PGPR treatments led to significant increases in total anthocyanin, total flavonoid, chlorophyll b, and total chlorophyll contents compared to the untreated control. Additionally, it has been reported that the application of indole-3-acetic acid (IAA)-producing and phosphate-solubilizing bacteria (*Pseudomonas fluorescens* RC512, *Bacillus megaterium* RC16, and *Bacillus subtilis* RC17), either individually or in combination, significantly increased plant height, seed weight, and number of branches in *Nigella damascena* (Akçura and Çakmakçı, 2023).

Although research on IAA-producing bacteria in the rhizosphere has increased recently, studies on the medicinal plant rhizosphere are still limited. The latest research underscores the importance of advancing the development of microbial formulations using local isolates that demonstrate activity across diverse rhizospheric ecosystems and plant species (Compant et al., 2019). Therefore, the development of microbial fertilizers that align with sustainable agricultural practices that contribute to environmental protection has the potential to substantially reduce the reliance on chemical fertilizers. This study aims to identify *Bacillus* spp. in the rhizosphere of the medicinal plant *S. officinalis*, widely used in medicine and pharmacy, and to determine their abilities to produce IAA and solubilize inorganic phosphate.

MATERIALS AND METHODS

Isolation and purification of rhizobacterial isolates

Rhizospheric soil samples were collected in May 2024 from medicinal sage in the Medicinal Plants Garden of the Department of Field Crops, Faculty of Agriculture (39°57'44.2"N, 32°51'36.7"E) Ankara University. The samples were taken from the plant rhizosphere at 3 different locations at a depth of 10 cm. Each soil sample was labeled and brought to the laboratory to study them under aseptic conditions. Rhizospheric bacteria were

isolated from 1 g of dried soil samples using the serial dilution technique. The soil samples were diluted in a series from 10^{-1} to 10^{-6}, and aliquots of each dilution were spread on to nutrient agar (NA) solidified Petri dishes. The plates were incubated at 28 °C, and distinct bacterial colonies were subsequently selected and subcultured many times until pure colonies were obtained (Figure 1).

Identification of rhizobacterial isolates

The physiological and biochemical characteristics of the bacterial isolates, along with Gram staining and endospore formation tests, were analyzed following the protocols described by Tsegaye et al. (2019). Rhizobacterial isolates, presumed to belong to the *Bacillus* genus and characterized as Gram-positive with spore-forming ability, were identified using the MALDI-TOF MS (Matrix-Assisted Laser Desorption Ionization Time-of-Flight Mass Spectrometry) technique. Microorganisms were identified based on their distinct molecular fingerprints using the MALDI Biotyper CA System. The protein profiles of microbial biomolecules, including proteins, peptides, sugars, and polymers, were ionized and subjected to an electric and/or magnetic field. The resulting spectral profiles were compared graphically to reference data in the system's database, allowing for precise identification at the genus and species level (Sivri and Öksüz, 2019). Figure 1 shows the flowchart of the process obtained from the isolation of *Bacillus* spp. from *S. officinalis* rhizospheric soil sample to determine their IAA-producing and phosphate-solubilizing properties.

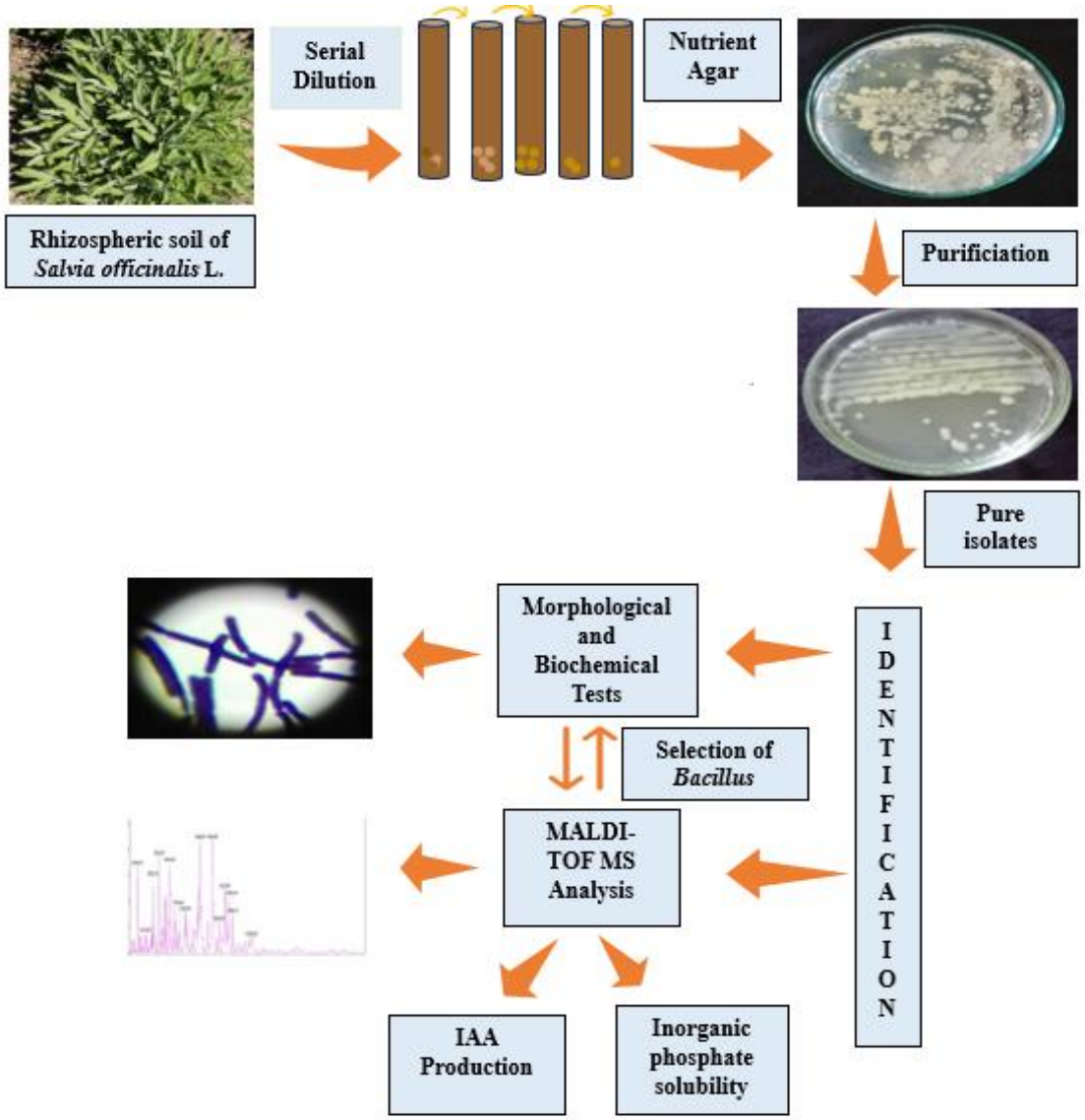

Figure 1. Process flowchart for identification and characterization of *Bacillus* spp. isolates from *S. officinalis* rhizospheric soil samples

Determination of inorganic phosphate dissolving isolates

The bacterial isolates were tested for their ability to solubilize phosphate according to the methods of Pikovskaya (1948) using Pikovskaya agar (PKA) medium (0.2 g L^{-1} NaCl, 10 g L^{-1} glucose, 0.2 g L^{-1} KCl, 5 g L^{-1} $Ca_3(PO_4)_2$, 0.5 g L^{-1} $(NH_4)_2SO_4$, 0.1 g L^{-1} $MgSO_4 \cdot 7H_2O$, 0.002 g L^{-1} $FeSO_4 \cdot 7H_2O$, 0.5 g L^{-1} yeast extract, 0.002 g L^{-1} $MnSO_4 \cdot H_2O$, and 1000 ml distilled water). The plates were inoculated with bacteria and incubated at 28±2 °C for 7 days. Colony, forming a clear halo zone around them, indicating phosphate solubilization. The experiments were performed in triplicate. The Phosphate solubilization index (PSI) was determined using measurements taken after seven days of growth from a point inoculation on a PKA medium at 28±2 °C (Meena et al., 2015).

Solubilization index = (Colony diameter + Halo zone diameter)/Colony diameter

Determination of Indole-3-Acetic Acid (IAA) producing isolates

The ability of the isolates to produce Indole-3-Acetic Acid (IAA) was evaluated following the protocol by Sarwar and Kremer (1995). The production of IAA was assessed in cultures grown in nutrient broth (NB) medium supplemented with 0.2 % L-tryptophan, incubated at 30 °C with shaking at 200 rpm for 4 days. One milliliter of culture was sampled every 24 hours and stored at -20 °C for analysis. Following the method outlined by Gang et al. (2019), 100 µL of Salkowaski reagent ($FeCl_3$, 0.5 M; $HClO_4$, 35%) was combined with an equal volume (100 µL) of the culture supernatant (obtained by centrifuging at 10,000 rpm for 5 min) in a 96-well microplate. The mixture was incubated in the dark at room temperature for 30 minutes. After the color developed, the absorbance of the mixture was measured spectrophotometrically (SHIMADZU UV mini-1240 Spectrophotometer) at 530 nm using both a standard curve created from known IAA concentrations and an uninoculated NB medium as controls.

Statistical analysis

Phosphate solubilization index (SI) and IAA production data were analyzed in triplicate using JMP Pro 17.0 statistical software. Dependent variables with a normal distribution were presented as mean ± standard deviation (SD) (Genç and Soysal, 2018).

RESULTS AND DISCUSSION

Evaluation of morphological and biochemical properties of isolates

A total number of 21 isolates were obtained from the rhizospheric soil samples of *S. officinalis*. After screening, 9 isolates were tentatively identified as *Bacillus* sp. based on standard methods, including Gram staining (positive), catalase test (positive), endospore formation (positive), as outlined in Bergey's Manual of Systematic Bacteriology (Krieg and Holt, 1984). Thereafter, isolates were confirmed as *Bacillus* sp. using the MALDI-TOF MS method. According to the MALDI-TOF MS analysis results, this genus included *B. simplex* (BSM-1 and BSM-2), *B. cereus* (BCM-3 and BCM-4), *B. thuringiensis* (BTM-1), *B. niacini* (BN-5), *Bacillus* spp. (BLM-7), *B. mycoides* (BMM-9), *B. megaterium* (BGM-13). While the catalase test of all isolates was positive, the oxidase test was negative. Moreover, all isolates were capable of sporulation. Additionally, all other isolates tested positive for motility. The morphological and biochemical results of the isolates are presented in Table 1.

Table 1. Morphological and biochemical properties of *Bacillus* spp. isolated from the rhizosphere of *S. officinalis*

Strain no	Gram reaction	Shape	Colony color	Endospore formation	Catalase test	Oxidase test	Motility	MALDI TOF MS result	NCBI Number
BSM-1	+	Rod	white	+	+	-	+	*B. simplex*	1478
BCM-3	+	Rod	white	+	+	-	+	*B. cereus*	1396
BTM-1	+	Rod	white	+	+	-	+	*B. thuringiensis*	1428
BN-5	+	Rod	cream	+	+	-	+	*B. niacini*	86668
BSM-2	+	Rod	white	+	+	-	+	*B. simplex*	1478
BLM-7	+	Rod	white	+	+	Not Detected	+	*Bacillus spp.*	1386
BCM-4	+	Rod	white	+	+	-	+	*B. cereus*	1396
BMM-9	+	Rod	white	+	+	-	+	*B. mycoides*	1405
BGM-13	+	Rod	white	+	+	-	+	*B. megaterium*	1404

Note: +, positive; –, negative *

The MALDI-TOF MS identification method relies on detecting intracellular molecules, particularly ribosomal proteins, to classify microorganisms at the genus, species, and strain levels. This technique is recognized as one of the most reliable tools for identifying microbial species across disciplines like agriculture, food, and medicine, owing to its high accuracy and rapid results (Solntceva et al., 2021). Çelikten and Bozkurt (2018) employed the MALDI-TOF method to identify 120 bacterial isolates obtained from the wheat rhizosphere in their search on plant growth-promoting bacteria. Similarly, Öksel et al. (2022) utilized MALDI-TOF MS to identify bacterial species from wheat rhizospheres. Ünlü et al. (2023) used the MALDI-TOF MS technique to identify bacterial strains isolated from the alfalfa rhizosphere, classifying them into genera like *Bacillus*, *Pseudomonas*, *Stenotrophomonas*, *Lysinibacillus*, *Acinetobacter*, and *Enterobacter* in another study. Similarly, Güler, (2024) used the MALDI-TOF MS method to identify phosphate solubilizing bacteria in the rhizosphere of *Thymus vulgaris.*

Evaluation of inorganic phosphate-solubilizing and IAA-producing *Bacillus*

The results of present study revealed that out of all 9 isolated *Bacillus* genera, 5 *Bacillus* species gave a halo zone which means their ability of phosphate solubilizing . In the current study*, B. cereus* BCM-3*, B. thuringiensis* BTM-1, *B. niacini* BN-5*, B. cereus* BCM-4, *and B. megaterium* BGM-13 could dissolve inorganic phosphate (Figure 2B). P solubilization index of bacterial isolates was defined in between 3.94 to 6.58 on PKA (Pikovskaya medium) agar. According to the Phosphate solubilization index of bacterial isolates in PKA agar medium, the maximum phosphate solubilization index (PSI) value was obtained from *B. cereus* BCM-3 . This was followed by *B. cereus* BCM-4 and *B. megaterium* BGM-13 with PSI value of with PSI value of 6.35 and 5.21 respectively. The phosphate solubilization index (SI) of the isolates are shown in Figure 2A.

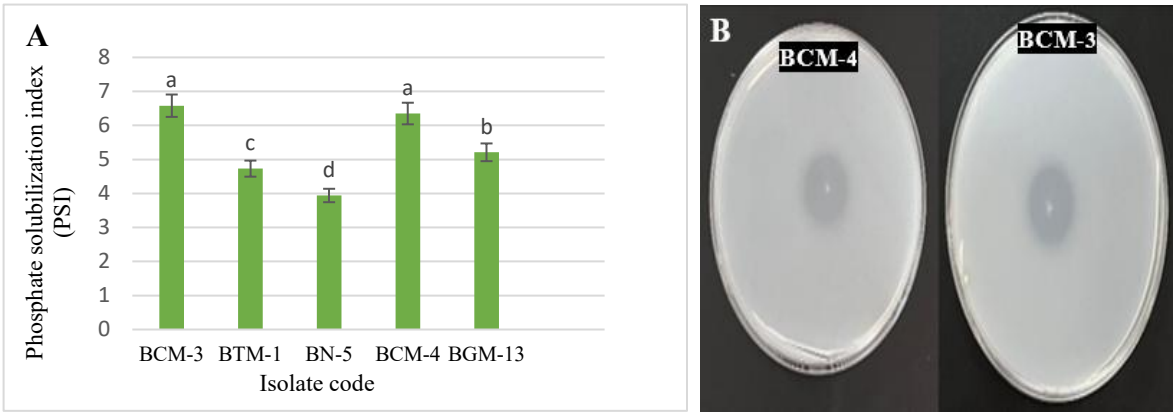

Figure 2. (A) Phosphate solubilization index (PSI) of five *Bacillus* sp. capable of dissolving inorganic phosphate in PKA medium over a 7-days period. (B) Phosphate-solubilizing bacteria formed transparent zones on PKA agar medium. All values are presented as the mean of three replicates. Bars labeled with different letters indicate statistically significant differences (p> 0.05). Error bars denote the standard deviation (SD) of the means.

Deficiency of phosphorus, is very crucial after nitrogen, and limit plant growth. Numerous microorganisms, including bacteria, fungi, actinomycetes, and algae, demonstrate the capacity to solubilize and mineralize phosphorus. Plant growth-promoting rhizobacteria (PGPR) facilitate enhanced phosphate uptake by plants by converting it from insoluble to soluble forms (Fahsi et al. 2021). Massucato et al. (2022) has mentioned that these bacteria provide phosphorus to plants through different mechanisms, with some relying on enzymatic processes (e.g., phytases and/or phosphatases) and others facilitating phosphorus availability via the extrusion of H^+ ions and the release of organic acids derived from microbial metabolisms. According to Rawat et al. (2021), the most prevalent phosphate-solubilizing *Bacillus* spp., *Enterobacter* spp., and *Pseudomonas* spp. available in the rhizosphere. Moreover, earlier studies have revealed *Bacillus* spp. as an effective phosphate solubilizer (Saeid et al., 2018; Gomez-Ramirez and Uribe-Velez, 2021). Abbas et al. (2019) has indicated that rhizospheric *Bacillus cereus* isolated from Iraqi soil dissolved phosphate by forming halo zones at high levels (100%). Kumar et al. (2020) determined that *B. cereus* LPR2 isolated from spinach rhizosphere is a very effective phosphate solubilizing bacteria, forming a large halo region (20 mm) in PKA medium. Soares et al. (2023) investigated phosphate solubilization index at different pH levels and determined that the rhizospheric *B. cereus* UFT42 exhibited a phosphate solubilization index (PSI) exceeding 3 across all tested pH ranges (7.0, 6.0, and 5.5). The variation in PSI may be linked to differences in the population of rhizospheric bacteria across diverse ecological

conditions, which could be influenced by various soil factors such as nutrient status, acidity, moisture content, organic matter, and soil enzyme activity. In the current study, the phosphate solubilization index of *B. cereus* BCM-3 and BCM-4 was determined as 6.58 and 6.35, respectively. Similar findings for *B. cereus* were reported by Arif et al. (2017) and Zhou et al. (2021).

Previous research has revealed that rhizospheric soil hosts a significantly larger population of phosphate-solubilizing bacteria when compared to non-rhizospheric soil (Linu et al., 2019; Ibáñez et al., 2021). Qureshi et al. (2012) has reported that *Bacillus megaterium* isolated from cotton rhizosphere had a solubilization Index of 3.8 using PKA medium. Fahsi et al. (2021) determined that the Inorganic P-solubilizing activity of *B. megaterium* J11 isolated from jujube rhizosphere in National Botanical Research Institute's (NBRIP) liquid medium was very low (20.5 mg L^{-1}) . Djuuna et al. (2022) reported that phosphate-solubilizing bacteria (PSB) comprise 50 % of the total microbial community in soil. Lin et al. (2023) reported that more than half of the *Bacillus* isolates obtained from soybean rhizosphere indicated phosphate-solubilizing activity. Among these isolates, *B. megaterium* P68 was found to solubilize phosphate at a rate of 461.86 mg L^{-1} after 7 days of incubation in NBRIP medium. On the other hand, the phosphate solubilization index of *B. megaterium* BGM-13 was determined as 5.21. Similar findings were noted for *B. megaterium* by Zhang et al. (2019) and Kang et al. (2021). Many studies have shown that rhizospheric *Bacillus thuringiensis* is an effective phosphate solubilizer (Delfim et al., 2018; Liu et al., 2021). AL Kahtani et al. (2020) documented that *Bacillus thuringiensis* exhibited phosphate solubilization efficiencies (PSE) ranging from 7.6 to 9.6 among 13 isolates derived from the rhizosphere of the medicinal plants *Fagonia mollis* and *Achillea fragrantissima*. Gaikwad et al. (2021) determined the phosphate solubilizing efficiency of soil-based *B. thuringiensis* in PKA medium as 5.6. The phosphate solubilization index of *B. thuringiensis* MMS-3 was determined as 3.1 in the present study.

IAA is a plant hormone that regulate root growth by promoting the division and elongation of root cells with root cap cuticles which protects the root meristem, induction of longer roots having more lateral hairy roots, which play a vital role in absorbing nutrients by the plants (Lau et al., 2020). The tested strains produced different levels of IAA depending on their growth in the NB medium supplemented with L-tryptophan. According to the results of the current study, 6 out of 9 *Bacillus* sp. were able to produce IAA at different rates (Figure 3). According to spectrophotometric analysis, the highest IAA production was indicated after 3 days using *B. cereus* BCM-3 with phosphate solubilization efficiency (PSE) of 129.8 µg ml^{-1}. This was followed by *B. cereus* BCM-4 with PSE of 114.5 µg ml^{-1} and *B. simplex* BSM-1 with PSE of 93.1 µg ml^{-1}, respectively. The lowest IAA production was determined in *B. thuringiensis* BTM-1 with PSE of 13.9 µg ml^{-1} on day 1. In comparison, *B. niacini* BN-5 and *B. simplex* BSM-2 yielded PSE of 18.1 µg ml^{-1} and 27.3 µg ml^{-1} of produced IAA, respectively, during the same incubation period. Figure 3 show experimental data for OD 530 nm and its equivalence in IAA (µg ml^{-1}) measured during different incubation periods.

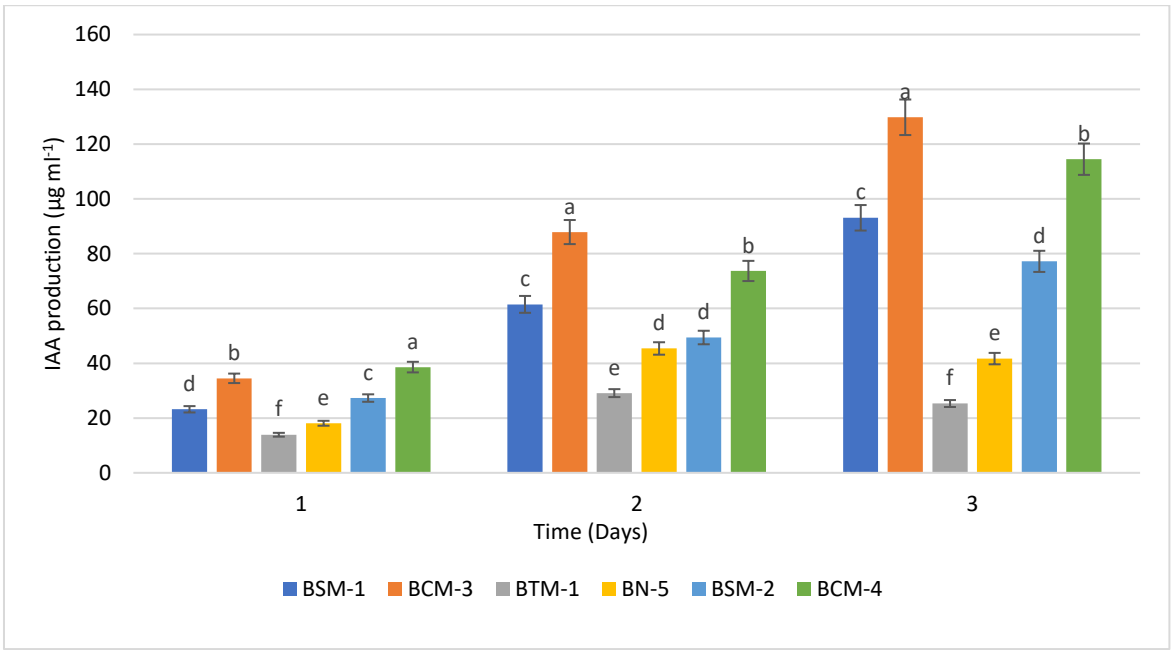

Figure 3. IAA production by the six *Bacillus* sp. cultured in nutrient broth supplemented with 0.2% L-tryptophan over a period of three days. All values are presented as the mean of three replicates. Bars labeled with different

letters indicate statistically significant differences (p> 0.05). Error bars denote the standard deviation (SD) of the means.

Several researchers have reported *Bacillus* spp. species from various plant roots to be good IAA producers (Miljaković et al., 2020; Ali et al., 2023). Sindhu et al. (2017) determined that *B. subtilis*, *B. flexus*, *B. cereus*, *B. megaterium*, and *B. endophyticus* produced IAA ranging from 4.0 to 24.3 µg ml^{-1}. Wagi and Ahmed (2019) determined that the rhizospheric isolate *B. cereus* (So3II) produced very high IAA (241.6 mg ml^{-1}) after 24 h of incubation. Hyder et al. (2020) reported that *B. cereus* KSL-24 isolated from chili pepper produced 56.2 µg ml^{-1} of IAA, while *B. cereus* KSL-8T produced 29.7 µg ml^{-1} of IAA. According to Widawati (2020), bacterial IAA production may not occur in the absence of L-tryptophan. In a recent study, Pakar et al. (2024) reported that rhizospheric *B. cereus* strain PM38 synthesized Indole 3-acetic acid (IAA) at a very high rate (166 µg ml^{-1}). In the current study, *B. cereus* BCM-3 and *B. cereus* BCM-4 isolates produced 129.8 and 114.5 µg ml^{-1} IAA after 3 days, respectively. The findings of our study are similar to Saboor et al. (2024), who determined IAA produced by *B. cereus* isolated from the *Vigna radiata* root.

Similar to other *Bacillus* species, *Bacillus simplex* has been indicated as an efficient producer of IAA. For instance, Cochard et al. (2022) reported that endophytic *B. simplex* B26 and B33 isolated from *Solanum lycopersicum* root produced 35.3 and 61 µg m^{-1} IAA, respectively, after 48 h. Çakmakçı et al. (2023) determined that among fifteen bacterial strains isolated from various acidic rhizospheric soils, *B. simplex* RC236 and *B. simplex* TE142 produced 41.3 and 63.8 µg m^{-1} IAA, respectively. In a recent study, Thakur et al. (2024) determined that *B. simplex* isolated from the rhizosphere of *Crocus sativus* produced 74.8 µg ml^{-1} IAA. Similarly, *B. simplex* BSM-1 and *B. simplex* BSM-2 isolates produced 93.1 and 77.2 µg ml^{-1} IAA after 3 days, respectively . Although there are studies on the plant growth promoting properties of *Bacillus niacini*, studies on its IAA production are limited. Cedeño-García et al. (2018) reported that *B. niacini* GN8 isolated from *Medicago sativa* rhizosphere produced IAA at low value (14.03 µg ml^{-1}). In a similar study, Alemneh et al. (2021) determined that rhizospheric *B. niacini* with phosphate solubilizing ability produced low value (<10 µg ml^{-1}) IAA. On the other hand, Abdullahi et al. (2022) reported that rhizospheric *B. niacini* SA3 produced high value (96.56 µg ml^{-1}) of IAA. *B. niacini* BN-5 produced 41.7 µg ml^{-1} IAA after 3 days in the current study. Our findings are consistent with the results of Widawati et al. (2024), who observed IAA producing *B. niacini* from *Santalum album*. There are many studies reporting that *Bacillus thuringiensis*, is particularly well known for its insecticidal activities. It also supports plant growth by producing IAA. For instance, Raheem et al. (2018) determined that *B. thuringiensis* D-2, isolated from the rhizosphere of drought-tolerant *Acacia arabica*, produced 5.6 µg ml^{-1} of IAA, as confirmed by HPLC analysis. Batista et al. (2021), investigated the effect of tryptophan (Trp) concentration on *B. thuringiensis* RZ2MS9 IAA production, determined that the application of 1 g L^{-1} Trp to the medium increased IAA secretion by the bacteria 5-fold. Figueredo et al. (2023) reported that the rhizospheric strain *B. thuringiensis* RZ2MS9 synthesized 4.59 µg ml^{-1} of IAA in a tryptophan-free medium, while the addition of 5 mM tryptophan to the medium increased IAA production to 7.67 µg ml^{-1}. Their findings are consistent with this study, in which 0.2 % tryptophan was added to the growth medium. *B. thuringiensis* BTM-1 produced 41.7 µg ml^{-1} IAA after 3 days in the current study. The results are in line with Esertaş et al. (2024), who reported that *B. thuringiensis* 5O9 isolated from the roots of *Phalaenopsis* spp. produced 11.66 µg ml^{-1} IAA.

CONCLUSION

Plant growth-promoting bacteria are biofertilizers that enhance plant growth, improve resistance to diseases, and increase soil fertility. Their use in agriculture offers an environmentally friendly and sustainable alternative by reducing the need for chemical fertilizers. This is first report about a bacterium isolated from *S. officinalis* rhizosphere in Turkiye. Studies on IAA-producing *Bacillus* species isolated from the rhizosphere of the medicinal plants are limited. *Bacillus cereus* BCM-3 and BCM-4 isolated from the rhizosphere of medicinal sage have significant potential as plant growth-promoting (PGP) agents in terms of their IAA production and inorganic phosphate solubilization abilities. To achieve a broader ecological assessment, it is necessary to compare isolates from different plant rhizospheres and investigate a wider range of bacterial species. Further research is needed to elucidate the molecular and functional characteristics of these two isolates in detail and to support their effective use in field conditions.

Declaration of interests

The author declares that there is no conflict of interest.

Author Contributions

Murat Güler: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; writing— original draft; writing—review and editing.

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Original Article

Determination of Some Nutrient Contents of Endemic Plant *Verbascum yurtkuranianum* (Schrophulariaceae)

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ABSTRACT

Verbascum yurtkuranianum (Schrophulariaceae) has been identified in the Ericek Neighborhood area of Bursa Province and requires very different ecological and physiological conditions. This study determined the elemental content of the aerial parts and root organs of the locally endemic Gök Sığırkuyruğu (*V. yurtkuranianum)* plant. The average macro nutrient contents obtained from the aerial parts of the locally endemic plant were found to be: nitrogen (N) 33.4 g kg^{-1}, phosphorus (P) 04.79 g kg^{-1}, potassium (K) 48.1 g kg^{-1}, calcium (Ca) 06.79 g kg^{-1} and magnesium (Mg) 06.07 g kg^{-1}. The micro nutrient contents were determined as and sodium (Na) 1350 mg kg^{-1}. iron (Fe) 107.2 mg kg^{-1}, copper (Cu) 4.75 mg kg^{-1}, manganese (Mn) 11.66 mg kg^{-1}, zinc (Zn) 58.7 mg kg^{-1}, and boron (B) 22.9 mg kg^{-1}. The average macro nutrient contents obtained from the root part were found to be: N 33.3 g kg^{-1}, P 07.37 g kg^{-1}, K 47.9 g kg^{-1}, Ca 04.29 g kg^{-1}, Mg 04.80 g kg^{-1}, Na 00.69 g kg^{-1}. The micro nutrient contents were calculated as Fe 450.8 mg kg^{-1}, Cu 13.97 mg kg^{-1}, Mn 11.42 mg kg^{-1}, Zn 128.1 mg kg^{-1}, and B 16.1 mg kg^{-1}.

Key words: Biodiversity, nutrient content, local endemic, *Verbascum yurtkuranianum*, habitat

Endemik Bitki *Verbascum yurtkuranianum* (Schrophulariaceae)'un Bazı Besin Elementi İçeriklerinin Belirlenmesi

ÖZ

Verbascum yurtkuranianum (Gök sığırkuyruğu), Bursa İli, Ericek Mahallesi Mevkii'nden çok farklı ekolojik ve fizyolojik özelliklere ihtiyaç duymaktadır. Çalışma ile, lokal endemik olan Gök sığırkuyruğu (*V. yurtkuranianum)* bitkisinin toprak üstü ve kök organlarının element içeriği belirlenmiştir. Lokal endemik bitkinin toprak üstü kısımlarından elde edilen ortalama makro besin elementi içerikleri; azot (N) %3.34; fosfor (P) %0.479, potasyum (K) %4.81, kalsiyum (Ca) %0.679, magnezyum (Mg) %0.607, olarak bulunurken, mikro element içerikleri sodyum (Na) 1350 mg kg^{-1}, demir (Fe) 107.2 mg kg^{-1}; bakır (Cu) 4.75 mg kg^{-1}, mangan (Mn) 11.66 mg kg^{-1}, çinko (Zn) 58.7 mg kg^{-1}; bor (B) 22.9 mg kg^{-1} olarak tespit edilmiştir. Kök kısmından elde edilen ortalama makro besin element miktarlarından N %3.33; P %0.737, K %4.79, Ca %0.429, Mg %0.480, Na %0.069 olarak, mikro besin element miktarları ise; Fe 450.8 mg kg^{-1}; Cu 13.97 mg kg^{-1}, Mn 11.42 mg kg^{-1}, Zn 128.1 mg kg^{-1}; B 16.1 mg kg^{-1} olarak hesaplanmıştır.

Anahtar kelimeler: Biyolojik çeşitlilik, besin elementi içeriği, lokal endemik, *Verbascum yurtkuranianum*, yetişme ortamı

INTRODUCTION

Our country harbors 75% of the plant species found in the European continent, with one-third of them being endemic. This high level of endemism places a great responsibility on our country in terms of biodiversity, particularly in the conservation of endemic and rare species (Haspolat et al., 2016; Özdeniz et al., 2017; Yücel et

al., 2023). More than half of the endemic species in Türkiye are struggling to survive due to population declines and reductions, making them species on the brink of extinction (Ekim et al., 2000; Dayan, 2013). In addition, the smuggling of biological resources out of Türkiye leads to the loss of our rare species, over which we have rightful claims. Therefore, identifying and protecting rare species in our country, gaining knowledge about them, preserving their habitats, and ensuring their sustainable use are of great importance (Öztürk and Yiğit, 2013; Anonymous, 2016). The conservation of biodiversity is essential for plants to continue their existence and sustain their life cycles (Bu, 2008). Therefore, understanding the characteristics of a plant intended for cultivation and propagating it accordingly is of great importance for its germination and survival (Öztürk and Yiğit, 2013; Cesur et al., 2017).

One of these endemic species is the *Verbascum yurtkuranianum*, a locally endemic species found in Bursa Province. The *Verbascum* genus is represented worldwide by approximately 360 species (Heywood, 1993) and in Türkiye by 255 species and 130 hybrids, 200 of which are endemic (Duman et al., 2020; Pervin et al., 2024). According to Kaynak et al. (2006), the plant can grow up to 90-107 cm in height, has a sturdy, erect, unbranched or sparsely branched stem, and its basal leaves have serrated edges, with both upper and lower surfaces being hairless and glossy. At the same time, it has been identified as the third *Verbascum* species with purple flowers (Çenil, 2007; Anonymous, 2016). This locally endemic species was discovered in Bursa Province, Gürsu District, on a sloped area along the roadside in the western part of Ericek Neighborhood (Kaynak et al., 2006). The fact that *Verbascum yurtkuranianum* has been identified at a specific altitude and within a limited area indicates that it requires distinct ecological and physiological conditions. The *Verbascum* genus, with an endemism rate of 85%, ranks second in Türkiye in terms of the number of endemic species (Erik and Tarıkahya, 2004). The destruction of natural vegetation for the establishment of settlements and urbanization has led to the formation of ruderal vegetation as plants adapt to new living conditions. Plants that adapt to these habitats are significant due to their ability to flower and complete their vegetation cycle in a short period, even under extremely unfavorable conditions. *Verbascum* species generally prefer regions with harsh living conditions to avoid competition with other species.

The large number of species within the *Verbascum* genus and their distribution across very different geographical regions, along with issues in identification and taxonomy, suggest that examining the structure of these species could contribute to their taxonomic classification (Küçük et al., 2021). In this study, seedlings of the sky Gök sığırkuyruğu (*Verbascum yurtkuranianum*) were planted in pots, and macro- and micronutrient contents of samples collected from both aerial parts and root parts before flowering were analyzed. The obtained data are expected to support the development of *ex situ* conservation strategies for *Verbascum yurtkuranianum* in Ericek Neighborhood, Gürsu District, Bursa Province. Additionally, it is anticipated that this research will contribute to a better understanding of the plant's structural composition and aid in the sustainable conservation of biodiversity.

MATERIALS AND METHODS

In the summer of 2024, seeds of the plant were collected from the area where it naturally occurs in Ericek Neighborhood, Gürsu District, Bursa Province, at the end of August (the plant's seed-setting period). The collected seeds were stored in the refrigerator until the planting date to prevent deterioration. The pots were filled with 10 kg of soil. The soil used has a slightly acidic reaction (pH 6.4), is salt-free (251 µS cm^{-1}), has very little calcareous (0.86%), has sufficient total nitrogen (0.135 %), available P (12.8 mg kg^{-1}) and K (255.0 kg da^{-1}). Microelements (Fe, Cu, Zn and Mn) in the soil were determined to be sufficient. For this reason, basic fertilization was not applied to the pots. The soil was taken as representative of the areas where endemic plant seeds were collected in the Ericek. On March 27, 2024, the seeds were sown in trays (5 trays with 104 cells each) in the greenhouse of the 2nd Regional Directorate of Nature Conservation and National Parks - Bursa Branch, where they were germinated. The seedlings of *Verbascum yurtkuranianum* were transplanted into thirty pots in the Soil Science and Plant Nutrition greenhouse of Uludağ University on June 8, 2024. Ten randomly selected plants were harvested on November 6, 2024.

After the seeds of *Verbascum yurtkuranianum* germinated and reached the seedling stage, they were treated with Maxim XL and Korsilex 50 WP every fifteen days to protect against diseases. Ten plants were randomly selected from thirty pots and harvested by uprooting them, without damaging the roots and stems of the plants. After the samples removed from the pots were washed three times with tap water to clean the soil, they were then rinsed three times with pure water and prepared for drying in the air circulation drying oven at the Soil Science and Plant Nutrition Laboratory of Uludağ University. The root and aerial parts samples of the plants were separated, dried in the oven at 65°C, ground, and treated with a mixture of nitric acid and perchloric acid (4:1 ratio) for analysis preparation. The macro and micronutrient contents of the prepared samples were

analyzed using ICP OES (Perkin Elmer OPTIMA 2100 DV) device (Kacar and İnal, 2010). The nitrogen content of the plant samples was determined by first burning the samples in a furnace according to the Kjeldahl method, and then distilling the burned samples in a distillation apparatus to measure their nitrogen content (Bremmer, 1965). Phosphorus content was determined using the vanadomolybdate-phosphoric acid yellow color method (Lott et al., 1956). The sodium, potassium, and calcium contents of *Verbascum yurtkuranianum* plant samples were determined using the Ependorf Elex 6361 Flame Photometer (Horneck and Hanson, 1998), while the magnesium and micronutrient(copper, iron, manganese, boron, and zinc) contents were determined using ICP OES (Isaac and Johnson, 1998).

RESULTS AND DISCUSSION

As a result of the chemical analyses, the lowest and highest macronutrient contents found in the aerial parts and root organs of *V. yurtkuranianum* were determined and are provided in Table 1.

Table 1. *Some macroelement contents found in the aerial parts and root organs of Verbascum yurtkuranianum*

Plant parts		N, g kg^{-1}	P, g kg^{-1}	K, g kg^{-1}	Ca, g kg^{-1}	Mg, g kg^{-1}
Aerial parts	Minimum	30.4	04.53	46.1	05.53	05.41
	Maximum	35.5	05.05	52.1	07.75	08.06
	Average	33.4	04.79	48.1	06.79	06.07
Root	Minimum	30.0	07.20	39.3	03.81	04.22
	Maximum	40.9	07.76	53.2	05.39	05.64
	Average	33.3	07.37	47.9	04.29	04.80

*: Results are the average of ten plants harvested (n=10).

The average macronutrient contents detected in the aerial parts organs of the plant were: N 33.4 g kg^{-1}, P 04.79 g kg^{-1}, K 48.1 g kg^{-1}, Ca 06.79 g kg^{-1}, Mg 06.07 g kg^{-1}. The average macronutrient concentrations detected in the root organs of the plant were: N 33.3 g kg^{-1}, P 07.37 g kg^{-1}, K 47.9 g kg^{-1}, Ca 04.29 g kg^{-1}, Mg 04.80 g kg^{-1} (Table 1). The average maximum N content found in the aerial parts organs of *Verbascum yurtkuranianum* was 35.5 g kg^{-1}, P content was 05.05 g kg^{-1}, K content was 52.1 g kg^{-1}, Ca content was 07.75 g kg^{-1}, Mg content was 08.06 g kg^{-1}. The average minimum N content of this locally endemic plant was found to be 30.4 g kg^{-1}, P content 04.53 g kg^{-1}, K content 46.1 g kg^{-1}, Ca content 05.53 g kg^{-1}, Mg content 05.41 g kg^{-1}. The maximum macronutrientcontents from the root samples of *V. yurtkuranianum* were: N 40.9 g kg^{-1}, P 07.76 g kg^{-1}, K 53.2 g kg^{-1}, Ca 05.39 g kg^{-1}, Mg 05.64 g kg^{-1}, while the minimum contents were: N 30.0 g kg^{-1}, P 07.20 g kg^{-1}, K 39.3 g kg^{-1}, Ca 03.81 g kg^{-1}, and Mg 04.22 g kg^{-1} (Table 1). It was determined that the average macronutrient contents obtained from the leaf and stem parts of the locally endemic species *V. yurtkuranianum* (Gök Sığırkuyruğu) were higher than those obtained from the root region. Leaves are the primary organs of the plant that best represent its nutrition in terms of photosynthesis, transpiration, and respiration (Bilgin et al., 2016; Yalçın, 2018). Therefore, the amount of nutrients in the leaves is crucial in determining the nutrient content of the plant (Kutbay et al., 2003; Kılıç et al., 2012). N, P, K, Ca, and Mg are macronutrients that need to be absorbed in large amounts from the soil for plant growth and development. The absorption of these nutrient elements from the soil also varies depending on the environment's temperature, soil composition, light availability, and competition with other plants (Özbucak et al., 2022).

As a result of the chemical analyses, the lowest and highest values of the micronutrient contents found in the aerial parts and root organs of *V. yurtkuranianum* were determined and are provided in Table 2.

Table 2. *Some micronutrients contents found in the aerial parts and root organs of Verbascum yurtkuranianum*

Plant Parts		Na, mg kg^{-1}	Fe, mg kg^{-1}	Cu, mg kg^{-1}	Mn, mg kg^{-1}	Zn, mg kg^{-1}	B, mg kg^{-1}
Aerial parts	Minimum	1080	71.3	2.95	10.84	44.8	19.9
	Maximum	1800	169.1	7.91	12.86	83.7	26.7
	Average	1350	107.2	4.75	11.66	58.7	22.9
Root	Minimum	570	199.1	8.87	9.83	97.2	14.8
	Maximum	870	874.8	19.64	13.82	166.1	17.7
	Average	690	450.8	13.97	11.42	128.1	16.1

*: Results are the average of ten plants harvested (n=10).

The average micronutrient contents detected in the aerial parts organs of the plant were: Na 1350 mg kg^{-1}, Fe 107.2 mg kg^{-1}, Cu 4.75 mg kg^{-1}, Mn 11.66 mg kg^{-1}, Zn 58.7 mg kg^{-1}, B 22.9 mg kg^{-1} (Table 2). The average micronutrient contents detected in the root organs of the plant were: Na 690 mg kg^{-1}, Fe 450.8 mg kg^{-1}, Cu 13.97 mg kg^{-1}, Mn 11.42 mg kg^{-1}, Zn 128.1 mg kg^{-1}, B 16.1 mg kg^{-1}. The maximum Na content found in the aerial parts organs of the plant was 1800 mg kg^{-1}, Fe content 169.1 mg kg^{-1}, Cu content 7.91 mg kg^{-1}, Mn content 12.86 mg kg^{-1}, Zn content 83.7 mg kg^{-1}, and B content 26.7 mg kg^{-1}. The minimum Na content detected in the aerial parts of the locally endemic *V. yurtkuranianum* plant was 1080 mg kg^{-1}, Fe content 71.3 mg kg^{-1}, Cu content 2.95 mg kg^{-1}, Mn content 10.84 mg kg^{-1}, Zn content 44.8 mg kg^{-1}, and B content 19.9 mg kg^{-1}. The maximum nutrient contents in the root samples of *V. yurtkuranianum* were: Na 870 mg kg^{-1}, Fe 874.8 mg kg^{-1}, Cu 19.64 mg kg^{-1}, Mn 13.82 mg kg^{-1}, Zn 166.1 mg kg^{-1}, and B content 17.7 mg kg^{-1}. In the study, the minimum nutrient contents in the root region of the plant were obtained as follows: Na 570 mg kg^{-1}, Fe 199.1 mg kg^{-1}, Cu 8.87 mg kg^{-1}, Mn 9.83 mg kg^{-1}, Zn 97.2 mg kg^{-1}, and B content 14.8 mg kg^{-1} (Table 2). In studies determining the relationships between the micronutrients in the soil and the plant, the normal ranges for Cu, Fe, Mn, and Zn elements in plants are defined as 5-30, 2-250, 30-300, 25-150 mg kg^{-1} (dry weight), while the toxic values are determined as 20-100, 400-1000, 300-500, 100-400 mg kg^{-1} (dry weight) (Güleryüz et al., 2010; Hilooğlu and Sözen, 2017; Kabata-Pendias and Mukherjee, 2007; Özdemir and Öztürk, 1996).

When the research results are compared with these values, it is observed that only Cu and Zn remain within the given limits, while the Mn content is below these values, and the average Fe content in the root organ is above the specified range. This indicates that *V. yurtkuranianum* accumulates Fe in its roots. The results are consistent with the studies conducted by researchers.

CONCLUSION

It has been determined that the average macronutrient contents (N, K, Ca, and Mg) in the aerial parts organs of the locally endemic *V. yurtkuranianum* plant are higher than the nutrient contents in the root organs. Only the average P content was higher in the roots than in the aerial parts organs. Among the average micronutrient contents of the plant, Fe, Cu, and Zn values were found to be higher in the roots, while the average Na, Mn and B contents were found to be higher in the aerial parts organs.

This is the first study investigating the macro and micronutrient contents of the locally endemic *V. yurtkuranianum* plant, located in an area of 2 km^2 in Ericek, Gürsu District, Bursa Province. It is believed that this study will provide an important contribution to the conservation of endemic species, which are threatened for various reasons, by identifying new habitats and enhancing the understanding of the species.

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Declaration of interests

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

Ferrin Ferda AŞIK: Conceptualization; data curation; formal analysis; investigation; methodology; writing-original draft; writing-review and editing.

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Original Article

Comparative Analysis of Trend Models for Standardized Precipitation Index (SPI) Data for Çanakkale

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ABSTRACT

Understanding precipitation trends is critical for assessing climate change and its impacts on water resources, and disaster preparedness. In this study it was aimed to analyzes the long-term trends of the Standardized Precipitation Index (SPI) for Çanakkale. The precipitation data from a period of 1929 to 2023 was used. Three distinct models—Linear Regression, Autoregressive Integrated Moving Average (ARIMA), and Long Short-Term Memory (LSTM) networks—were employed to evaluate SPI trends. The linear regression model indicated significant short-term fluctuations in SPI values but did not reveal a clear long-term trend toward wetter or drier conditions. The ARIMA model, optimized for stationarity, also suggested relatively stable precipitation patterns, with no pronounced directional trend over the study period. The LSTM model, designed for sequential data analysis, captured complex temporal dependencies in SPI values but did not indicate a persistent long-term trend. Instead, the results highlighted substantial interannual variability in precipitation. These findings underscore the complexity of climate patterns in Çanakkale Province and emphasize the need for diverse modeling approaches to accurately assess precipitation trends. The lack of a clear directional trend suggests that short-term climate variability plays a more significant role than long-term changes in precipitation patterns in the region. This study provides a foundation for further research into advanced modeling techniques to enhance climate prediction capabilities. Future studies should explore hybrid and ensemble methods to improve accuracy, which is crucial for climate adaptation strategies and water resource management.

Key words: ARIMA, Linear Regression, Long Short-Term Memory, Climate Variability, Precipitation Trends.

Çanakkale için Standart Yağış İndeksi (SPI) Verileri için Trend Modellerinin Karşılaştırmalı Analizi

ÖZ

Yağış eğilimlerini anlamak, iklim değişikliğini ve su kaynakları ile afetlere karşı hazırlığı etkileyen faktörleri değerlendirmek için kritik öneme sahiptir. Bu çalışmada Çanakkale için Standart Yağış İndeksi'nin (SPI) uzun vadeli eğilimlerini analiz etmek amaçlanmıştır. 1929-2023 dönemine ait yağış verileri kullanılmıştır. SPI eğilimlerini değerlendirmek için Doğrusal Regresyon, Otoregresif Entegre Hareketli Ortalama (ARIMA) ve Uzun Kısa Vadeli Bellek (LSTM) ağları olmak üzere üç ayrı model kullanılmıştır. Doğrusal regresyon modeli, SPI değerlerinde kısa vadeli önemli dalgalanmalar göstermiştir ancak daha yağışlı veya daha kuru koşullara doğru net bir uzun vadeli eğilim ortaya koymamıştır. Durağanlık için optimize edilmiş ARIMA modeli, çalışma dönemi boyunca belirgin bir yön eğilimi olmaksızın nispeten istikrarlı yağış desenleri de önermiştir. Sıralı veri analizi için tasarlanan LSTM modeli, SPI değerlerinde karmaşık zamansal bağımlılıkları yakalamış ancak kalıcı uzun vadeli bir eğilim ortaya koymamıştır. Sonuçlar yağışta önemli yıllık değişkenliği ortaya koymaktadır. Bu bulgular, Çanakkale İli'ndeki iklim modellerinin karmaşıklığını vurgulamakta ve yağış eğilimlerini doğru bir şekilde değerlendirmek için çeşitli modelleme yaklaşımlarına olan ihtiyacı ortaya koymaktadır. Net bir yön eğiliminin olmaması,

kısa vadeli iklim değişkenliğinin bölgedeki yağış modellerindeki uzun vadeli değişikliklerden daha önemli bir rol oynadığını göstermektedir. Bu çalışma, iklim tahmin yeteneklerini geliştirmek için gelişmiş modelleme tekniklerine yönelik daha fazla araştırma için bir temel sağlamıştır. Gelecekteki çalışmalar, iklim adaptasyon stratejileri ve su kaynakları yönetimi için çok önemli olan doğruluğu artırmak için hibrit ve topluluk yöntemlerini araştırmalıdır.

Anahtar kelimeler: ARIMA, Doğrusal Regresyon, Uzun Kısa Dönemli Bellek, İklim Değişkenliği, Yağış Eğilimleri.

INTRODUCTION

Studying precipitation trends is vital in climate science due to its significant impact on various environmental and societal aspects. Precipitation patterns influence water resources, agriculture, ecosystems, and urban planning, making it crucial to understand and predict these trends accurately. Analyzing spatial patterns of precipitation trends helps in understanding regional climatology and preparing for climatic changes. For example, research on the continental United States identified hotspots of increasing and decreasing precipitation trends, which can guide regional planning and adaptation strategies (O'Brien, 2018). Accurate prediction of precipitation trends is crucial for economic development as well. Studies in the Swat River basin, Pakistan, showed variability in precipitation trends across different time scales, highlighting the importance of precise predictions for water resource management and agricultural planning (Ahmad et al., 2015). On a global scale, mapping minimal detectable trends in annual precipitation is highly important for assessing the impact of climate change. This helps in identifying regions at risk and formulating global adaptation strategies (Morin, 2011). Detecting overlooked trends in precipitation, especially in extreme events, is critical for risk management in agriculture, water supply, and ecosystems. Quantile regression analyses have revealed significant trends in extreme precipitation that traditional methods might miss (Lausier & Jain, 2018). Precipitation trends directly affect the hydrological cycle and water management policies. Studies in Turkey demonstrated that understanding the spatial and temporal variations of precipitations is critical for effective management of water resources (Yavuz & Erdogan, 2012). Studying trends in precipitation alongside temperature helps predict future climate scenarios. Joint modeling of these parameters provides more accurate predictions of climate impacts, which are essential for planning and adaptation (Mesbahzadeh et al., 2019).

In this study it was aimed to monitor Standardized Precipitation Index (SPI) trends for further understanding and mitigating the impact of climate change. To achieve this objective three different approaches in modeling and predicting SPI data are employed using long term (1929 – 2023) precipitation data.

MATERIALS AND METHODS

Study Area and Dataset

Çanakkale province is located at of 39°27' north latitude and 26°16' east longitude (Figure 1). These coordinates show that the province is in the northwest of Turkey, bordering the Aegean and the Marmara Seas (Ünsal, 2015). Çanakkale has a climate that is transitional between the Mediterranean climate and the Black Sea climate. A warm and temperate climate prevails throughout the province. The average annual temperature is around 15°C. Summer months are hot and dry. In July and August, temperatures often rise above 30°C. Winters are warm and rainy. The average temperature in January varies between 5-10°C. Snowfall is rare, it usually rains. The mean precipitation varies between 600-700 mm. Precipitation generally occurred in fall and winter (Kale, 2017).

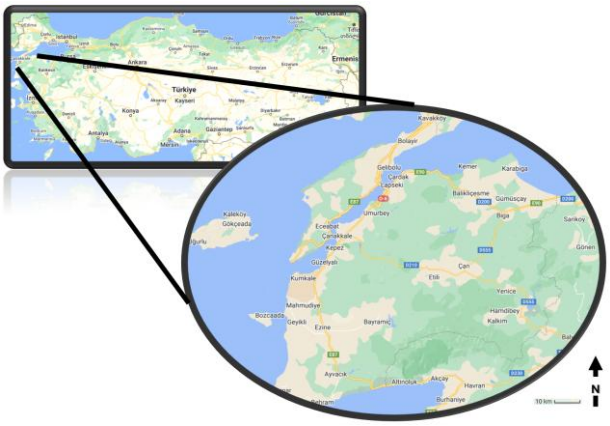

Figure 1. Study area

Montly precipitation data for the years 1929 - 2023 were obtained from the Turkish State Meteorological Service. The file containing precipitation data also includes data from all stations in the country. Therefore, first of all, only information about Çanakkale meteorology station was extracted from the txt file. These data were then converted into an Excel file and made ready for statistical analysis. Statistical calculations were made in Python programming language. Libraries such as Keras, Tensorflow, Sklearn, NumPy and Panda were used in the analyses. Necessary coding for trend analysis was done on Google Colab.

Standardized Precipitation Index (SPI)

The SPI is a commonly used technique designed to quantify precipitation deficits within different time scales. It provides a probabilistic measure of precipitation anomalies. Its calculation requires a historical data that fits probability distribution followed by transformation into a normal distribution. This allows the SPI to express the precipitation deficit or surplus as standard deviations from the mean. The commonly used probability distribution for SPI calculation is the gamma distribution, but other distributions such as normal, log-normal, and Weibull can also be employed based on the region and time scale (Angelidis et al., 2012). It can be calculated for different time scales, mainly from 1 to 48 months. Time scale of 1-6 months are useful for agricultural droughts, time scales of 12-48 months are better for hydrological droughts (Guenang & Kamga, 2014).

In this study it was aimed to monitor hydrological drought. Therefore, 12-month time scale was used for SPI calculations. The 12-month SPI integrates seasonal and interannual variability, providing a more stable and smoothed indicator of precipitation anomalies that directly impact water resource availability, reservoir levels, and watershed-scale hydrology. Additionally, focusing on a single, longer time scale reduced the dimensionality and complexity of model comparisons, allowing a clearer evaluation of the models' performance in capturing meaningful long-term climate signals. To fit a probability distribution, two-parameter gamma equation was used due to its flexibility and suitability for precipitation data (Equation 1) (Blain & Meschiatti, 2015).

$$f(x) = \frac{x^{\alpha-1} e^{-x/\beta}}{\beta^{\alpha}\Gamma(\alpha)} \quad (1)$$

Where; x is the variable of interest, which is the value at which the probability density function (PDF) is evaluated (precipitation amount), α is the shape parameter, β is the scale parameter, Γ is the gamma function, and e is the base of the natural logarithm.

Then, cumulative probabilities of each precipitation value were computed by using Equation (2).

$$G(x) = \int_0^x \frac{t^{\alpha-1} e^{-t/\beta}}{\beta^{\alpha}\Gamma(\alpha)} dt \quad (2)$$

Where; G(x) is the cumulative distribution function (CDF), t is variable of integration, which represents all possible values up to x, α is the shape parameter.

Finally, the cumulative probability transformed into standard normal distribution. This is done by the inverse normal (Gaussian) function (Equation 3).

$$SPI = \Phi\text{-}1(G(x)) \quad (3)$$

Where; Φ−1 represents the inverse function of the standard normal cumulative distribution.

Trend Analysis

Linear regression model

Linear regression is a fundamental statistical tool used to analyze and interpret trends in different fields. Linear regression models are employed to define relationships between an outcome (dependent) variable and one or more input (independent) variables. The fundamental equation governing this relationship is presented in Equation (4).

$$Y=\beta 0+\beta 1X+\epsilon \quad (4)$$

Where; Y represents the dependent variable while X represents the independent variable. β0, β1, and ϵ are the intercept, slope and error term, respectively.

Autoregressive integrated moving average (ARIMA)

In environmental sciences, ARIMA models are used to analyze trends in climatic data, such as precipitation and temperature patterns, which are crucial for understanding climate change impacts and planning mitigation strategies (Dimri et al., 2020). These models are characterized by three key parameters: p (autoregressive order), d (differencing order), and q (moving average order), and are generally represented as ARIMA(p,d,q). The Autoregressive (p) component signifies that the variable of interest is predicted based on its past values. The integrated (d) component accounts for differencing the raw data to achieve stationarity in the time series. Lastly, the moving average (q) component identifies the relationship between an observed value and the residual errors. The general equation for the ARIMA model is presented in Equation (5).

$$Yt=c+\phi 1Yt-1+\phi 2Yt-2+...+\phi pYt-p+\theta 1\epsilon t-1+\theta 2\epsilon t-2+...+\theta q\epsilon t-q+\epsilon t \quad (5)$$

Where; Yt represents the value at time t, c is a constant, ϕi are the coefficients for the autoregressive terms, θj are the coefficients for the moving average terms, and ϵt is the error term at time t (Green & Noles, 1977).

The best model parameters are determined using the AIC (Akaike Information Criterion), and the combination of (p, d, q) which yields the lowest value is defined as the optimal model. Zhang & Meng, (2023) demonstrates the application of AIC in the selection of ARIMA model parameters, balancing model complexity and accuracy. The AIC criterion aids in selecting the optimal model by minimizing its value, ensuring the best combination of (p, d, q) is chosen.

Using the ADF test's p-value and ADF statistics it was evaluated that if the data is stationary. If this value is less than a threshold value (commonly 0.05), this means that the data is likely stationary. Additionally, if the ADF test statistic is more negative than the critical values at different significance levels (1%, 5%, 10%), it indicates that the data is stationary. In summary, a low p-value (typically less than 0.05) or an ADF statistic more negative than the critical value suggests that both data are stationary.

Long Short-Term Memory Networks (LSTM)

LSTMs are a type of recurrent neural networks (RNNs). This advanced type is developed to handle the shortcomings of traditional RNNs. They perform well in managing long-term dependencies. They are highly effective for sequential data tasks, such as time series analysis (Oruh et al., 2022).

LSTM networks consist of multiple units, each incorporating a cell, an input gate, an output gate, and a forget gate. The traffic of information within the network is controlled by these gates, enabling LSTMs to efficiently retain and update long-term dependencies. They operate by iteratively processing input sequences through the gates and cell states. The primary equations governing an LSTM unit at time step t are given in following Equations (6, 7, 8, 9, 10, 11).

$$ft=\sigma(Wf\cdot[ht-1,xt]+bf) \quad (6)$$

Where; ft represents the forget gate activation at time step t, σ denotes the Sigmoid activation function, Wf is the weight matrix associated with the forget gate, $ht-1$ is hidden state from the previous time step $t-1$, xt is input at the current time step t, and bf is bias for the forget gate.

$$it=\sigma(Wi\cdot[ht-1,xt]+bi) \quad (7)$$
$$\acute{C}t=\tanh(WC\cdot[ht-1,xt]+bC) \quad (8)$$

Where; it is input gate activation at time step t, Wi is weight matrix for the input gate, bi is bias for the input gate, $\acute{C}t$ is candidate cell state at time step t, tanh is hyperbolic tangent activation function, WC is weight matrix for the candidate cell state, and bC is bias for the candidate cell state.

$$Ct=ft\cdot Ct-1+it\cdot\acute{C}t \quad (9)$$

Where; Ct is updated cell state at time step t, ft is forget gate activation at time step t, $Ct-1$ is cell state from the previous time step $t-1$.

$$ot=\sigma(Wo\cdot[ht-1,xt]+bo) \quad (10)$$
$$ht=ot\cdot\tanh(Ct) \quad (11)$$

Where; ot is output gate activation at time step t, Wo is weight matrix for the output gate, ht−1 is hidden state from the previous time step t−1, xt is input at the current time step t, bo is bias for the output gate, ht is hidden state or output of the LSTM unit at time step t, Ct is cell state at time step t.

The statistical parameters of LSTM networks, such as weights, biases, activation functions, learning rate, number of units, batch size, and dropout rate, play a highly important role in their performance. Understanding and optimizing these parameters is essential for leveraging the full potential of LSTM networks in various applications (Merity et al., 2017).

RESULTS AND DISCUSSION

Linear Regression Model

12-month SPI and trend line drawn via linear regression model are represented in Figure 2. The SPI values exhibit significant fluctuations, indicating variability in annual precipitation with periods of both wetter and drier conditions. On the other hand, the nearly horizontal red trend line indicates that, on average, there is no significant increase or decrease in annual SPI values over the observed period. This implies that there is no strong indication of wetter or drier conditions for the long term.

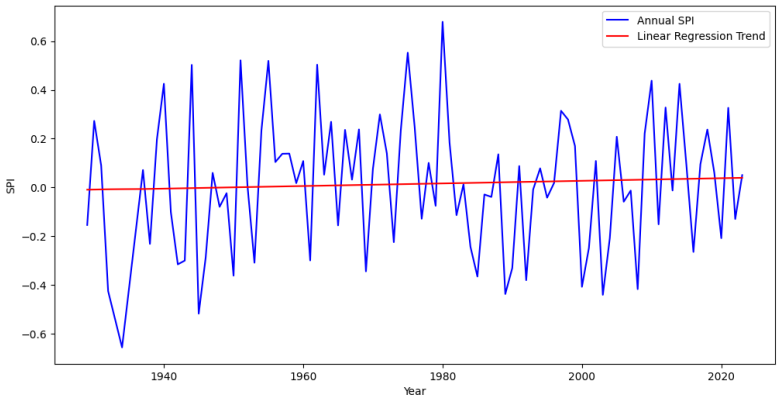

Figure 2. Annual SPI trend analysis with linear regression

The statistics for the linear regression model are listed in Table 1. Given in Table 1, a highly small R2 value suggesting that the linear trend does not capture much of the variability in the data. Additionally, a relatively low MSE value indicates that the model's predictions closely align with the actual values on average. Another parameter is the slope of the linear regression model. The small positive slope indicates a slight upward trend in SPI values over time, but the trend is very minimal.

Table 1. Linear regression model statistics

Parameter	Value
R^2	0.00297
Mean Squared Error (MSE)	0.07507
Slope	0.00056
Intercept	-1.08741

The linear regression analysis reveals no substantial long-term trend in the annual SPI values. The natural variability in annual precipitation remains the dominant feature of the SPI data.

ARIMA Analysis

After calculating the annual SPI values (Figure 2), an ARIMA trend analysis was conducted. Important model parameters in this analysis are defined by the letters (p, d, q) as explained above. Using Python's itertools library, the optimal parameters that yield lowest AIC value were attempted to be determined by trial-error method. However, the iteration resulted in (0,0,0) values, indicating that the data is non-stationary. Stationarity is highly important for ARIMA, because these models assume that the statistical properties of the series are not changed. To convert the data from non-stationary to stationary form, differencing was applied. After differencing, the data appeared as given in Figure 3.

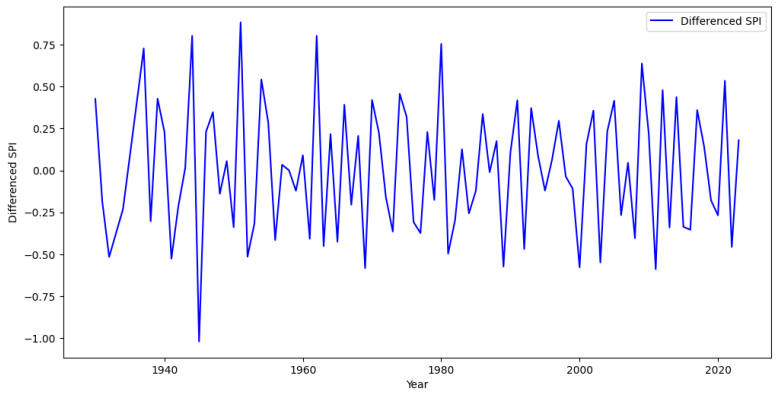

Figure 3. Differenced annual SPI data

Stationarity of original and differenced data was evaluated using the Augmented Dickey-Fuller (ADF) test. The results are listed in Table 2.

Table 2. ADF test statistics

	Value	
Parameter	**Original Data**	**Differenced Data**
ADF Statistic:	-9.59	-6.055
p-value:	2.04×10^{-16}	1.25×10^{-7}
Critical Values:		
1%:	-3.50	-3.51
5%:	-2.89	-2.90
10%:	-2.58	-2.59

Based on the test statistics an ARIMA model without differencing was used as the data does not require differencing.While the test results indicate that the original data is stationary, the inability to fit ARIMA models effectively on the original data suggests that there might be other factors at play, such as higher-order dependencies or non-linearities that are not captured by simple ARIMA models without differencing. As a result, differenced data is used to run ARIMA model. Once the iteration process was applied (1,1,1) model fitted well on the differenced data. Therefore ARIMA (1, 1, 1) model was applied. The ARIMA model output and differenced SPI data plot are given in Figure 4.

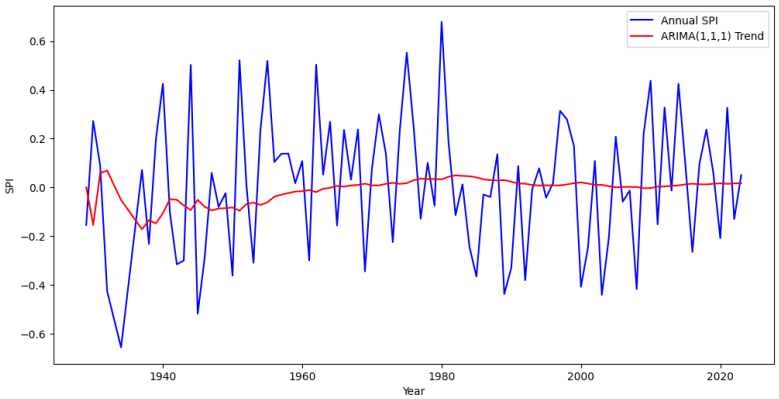

Figure 4. Annual SPI trend analysis with selected ARIMA model

Based on ARIMA, the trend line appears relatively flat with minor fluctuations over the years. This flat trend line suggests that there is no significant long-term trend in the SPI values, indicating either wetter or drier conditions over the entire period. In early years (Pre-1950s) the SPI values exhibit high variability with noticeable peaks and troughs. The red trend line shows a slight downward trend initially, indicating drier conditions during this period.

However, during mid to late period (Post-1950s) the SPI values continue to show variability, but the fluctuations become more moderate. The red trend line flattens out and remains close to zero, indicating that there is no

strong indication of wetter or drier conditions for this period. The ARIMA (1, 1, 1) model indicates that the annual SPI values have not shown a consistent long-term trend towards wetter or drier conditions over the years. The conditions appear relatively stable, with fluctuations that do not point towards a significant change in either direction.

Long Short-Term Memory (LSTM) Networks Analysis

Used as a version of recurrent neural networks that is particularly good at learning from sequences and temporal data, making it applicable for time series analysis. Improving the performance of an LSTM model can involve several strategies, including tuning hyperparameters, increasing model complexity, adding regularization, and improving data preprocessing. In order to find the select best LSTM parameters, Keras' optimizer library was employed. Based on the optimization (tuning hyperparameters) following model was developed representing the SPI data trend (Table 3).

Table 3. LSTM model parameters

Parameter	Value
Validation loss	0.0272
Units in the first layer	64
Units in the second layer	160
Dropout rate for first layer	0.2
Dropout rate for second layer	0.3
Number of layers	3
Learning rate	0.0025

Based on Table 3, A lower validation loss indicates better generalization and model performance. The number of units (neurons) in the first LSTM layer having 64 units means that the layer has 64 LSTM cells, each with its own set of weights and biases to learn from the data. Similar to the first LSTM layer, the number of units in the second LSTM layer having 160 units suggests that this layer is larger and might be capturing more detailed temporal patterns from the data. A dropout rate of 0.2 means that 20% of the neurons in the first LSTM layer are randomly dropped during each epoch, forcing the model to learn redundant representations and improve its generalization ability. Similarly, this dropout rate is applied to the second LSTM layer. A rate of approximately 0.3 (30%) means that 30% of the neurons in this layer are randomly dropped during training. The number of layers indicates the total number of layers in the model. In this case, the optimal number is 3, which typically includes the two LSTM layers and one additional layer (often a Dense layer) for the final output. A learning rate of approximately 0.002465 means the optimizer (Adam) will update the model weights by this fraction of the gradient. Selecting an appropriate learning rate is essential for model performance. If the learning rate is too high, the model may converge too quickly to a suboptimal solution, whereas a low learning rate can lead to an overly slow training process. Utilizing this optimized model, the trend analysis obtained through LSTM is presented in Figure 5.

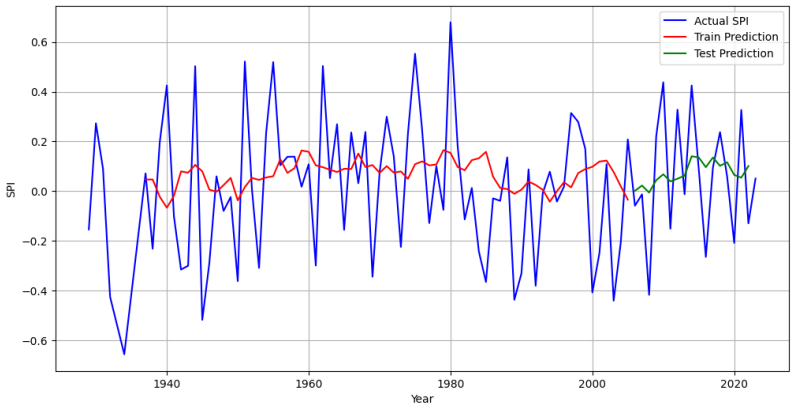

Figure 5. Improved annual SPI trend analysis with LSTM

As stated above the SPI values fluctuate significantly, indicating periods of both wet and dry conditions. The red line, on the other hand, represents the predicted values. The model reflects some general trends in the training data, but there are some deviations from the actual SPI values. It also seems to smooth out some of the higher peaks and lower troughs, indicating that it captures the overall trend but might miss some short-term

fluctuations. The green line, representing the model's predictions on the test dataset, follows the general trend of the actual SPI values reasonably well, with some deviations. The performance of the model on the test set indicates it has generalized well to unseen data, though it still shows some smoothing of extreme values. The overall trend captured by the LSTM model does not show a clear and consistent long-term increase or decrease in SPI values, which would indicate a significant trend towards wetter or drier conditions. There are periods of negative SPI values, but these are interspersed with periods of positive SPI values, indicating a balance between wet and dry periods over time. As a result, based on the trend analysis, there is no clear long-term trend towards drought in the given SPI data. The SPI values fluctuate around zero, indicating alternating periods of wet and dry conditions without a significant downward trend.

Ahmad et al. (2015) determined high variability in SPI trends in the Swat River basin using non-parametric tests, stating that precipitation trends are better explained with flexible and dynamic modeling rather than static linear methods. Yavuz & Erdogan (2012) also determined strong spatial and temporal variability in Turkish precipitation records with no consistent trends between areas, which corroborated the theory that local influences have a tendency to overpower larger-scale climate signals.

At the global level, Morin (2011) highlighted that the few discernible trends in annual precipitation are overshadowed by huge interannual variability, a result mimicked in this study's outcome of SPI trends fluctuating around a zero mean with no directional trend. In addition, Lausier & Jain (2018) demonstrated how traditional statistical approaches can overlook subtle trends, especially in extremes, which further validates the manuscript's use of advanced models like LSTM in identifying subtle trends.

Model Performance Evaluation and Statistical Comparison

To enhance the comparative evaluation of the three models, additional performance metrics—Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and the coefficient of determination (R^2)—were calculated (Table 4). The Linear Regression model had the poorest performance, with RMSE of 1.867, MAE of 1.693, and a negative R^2 value of -2.508, indicating that it failed to capture the variation in SPI values. In contrast, both the ARIMA and LSTM models yielded substantially better metrics, with nearly identical RMSE (0.998 for ARIMA, 0.996 for LSTM) and MAE (0.791 for ARIMA, 0.790 for LSTM), though their R^2 values remained close to zero (−0.0031 and 0.0004 respectively), suggesting limited predictive strength in terms of explained variance.

Table 4. Model Performance Metrics

	RMSE	MAE	R^2
Linear Regression	1.8669	1.6923	-2.5089
ARIMA	0.9982	0.7912	-0.0031
LSTM	0.9964	0.7902	0.0004

To statistically assess the difference in forecast accuracy, the Diebold-Mariano (DM) test was applied (Table 5). The test showed statistically significant differences between Linear Regression and both ARIMA (DM = 27.83, $p < 0.001$) and LSTM (DM = 27.91, $p < 0.001$). However, the difference between ARIMA and LSTM was not statistically significant (DM = 0.61, $p = 0.54$). These results confirm that while ARIMA and LSTM models outperform Linear Regression, their relative predictive performance is statistically similar. Therefore, both ARIMA and LSTM offer more reliable modeling options for SPI trend analysis in Çanakkale.

Table 5. Diebold-Mariano Test Results

	DM Statistic	p-value
LR vs ARIMA	27.8322	0.0000
LR vs LSTM	27.9088	0.0000
ARIMA vs LSTM	0.6104	0.5417

CONCLUSION

This study meticulously analyzed the Standardized Precipitation Index (SPI) for Çanakkale using three distinct models—Linear Regression (LR), Autoregressive Integrated Moving Average (ARIMA), and Long Short-Term Memory (LSTM)—spanning the period from 1929 to 2023. The findings reveal that none of the models identified a strong, consistent long-term trend in precipitation, highlighting the complex and variable nature of climate patterns in the region.

Quantitative performance metrics further clarified the relative effectiveness of the models. Linear Regression exhibited the weakest performance, with the highest RMSE and MAE values and a strongly negative R^2, indicating its inability to capture the underlying variability in SPI. In contrast, both ARIMA and LSTM models achieved significantly lower error rates and nearly identical performance, though their R^2 values remained close to zero. The Diebold-Mariano statistical test confirmed that both ARIMA and LSTM significantly outperformed Linear Regression in forecasting accuracy ($p < 0.001$), while no statistically significant difference was found between ARIMA and LSTM ($p = 0.54$).

The analysis carried out here took into consideration trend modeling of SPI values based on local precipitation only, ignoring overall atmospheric or oceanic climate forcing factors. Thus, the lack of persistence in a long-term trend in SPI does not necessarily imply climatic stability, but is instead a reflection of the non-availability of modulating variables that effect precipitation variability on interannual to decadal timescales. Climate indices such as the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO), and the El Niño-Southern Oscillation (ENSO) have been seen to influence regional precipitation traits over Europe and the eastern Mediterranean, including Turkey. For example, positive and negative phases of the NAO have been shown to be related to wetter or drier conditions in western Anatolia. Leaving these indices out may then minimize SPI trend interpretation to disregard such important teleconnections that could be primarily behind the interannual variability observed. Although no statistically significant long-term trend towards increasing or decreasing precipitation based on SPI-12 analysis was detected in this research, the fact of substantial interannual variability renders adaptive water management essential to Çanakkale. Policy makers need to put top priority on the development of variable drought preparedness policies capable of responding to short-term variations over the single strategy of long-term prediction. Investments should be made in climate-resilient infrastructure, such as multi-year water storage infrastructure, to serve as a cushion against unpredictable dry years.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

The authors declare that they have contributed equally to the article.

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Original Article

Determination of Genotype × Environment Interaction for Seed Yield in Oilseed Flax (*Linum usitatissimum* L.) Genotypes

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ABSTRACT

This research investigated the performance of oilseed flax (*Linum usitatissimum* L.) genotypes cultivated under varying conditions in Edirne province during 2023 and 2024, focusing on grain yield and Genotype x Environment (GE) interactions by various analytical approaches. Fifteen genotypes were used in the study. The trials were conducted using a randomized complete block design with three replications. To assess the stability of genotypes regarding grain yield, the following parameters were employed: $S^{(1)}$, $S^{(2)}$, $S^{(3)}$, $S^{(6)}$, $NP^{(1)}$, $NP^{(2)}$, $NP^{(3)}$, $NP^{(4)}$, W_i^2, σ^2_i, s^2d_i, b_i, CVi, $\theta_{(i)}$, θ_i, KR parameters, and GGE biplot analysis. The analysis of variance indicated that genotypes, environments, and genotype-environment interaction exerted highly statistically significant impacts ($p<0.01$) on grain yield. The stability assessments revealed that the G5 genotype distinguished itself through superior yield and stability, while the G10 and G6 genotypes had high grain yield and broad adaptability. The GGE biplot analysis indicated that these genotypes exhibited extensive adaptability and effectiveness of some environments in distinguishing between them.

Key words: Flax varieties, stability, genotypes, seed yield, GGE-biplot

Yağlık Keten (*Linum usitatissimum* L.) Genotiplerinde Tane Verimi Yönünden Genotip x Çevre İnteraksiyonunun Belirlenmesi

ÖZ

Bu araştırmada 2023 ve 2024 yılında Edirne ilinde farklı koşullarda yetiştirilen yağlık Keten *(Linum usitatissimum* L.*)* genotiplerinin tane verimi yönünden performansları ve Genotip x Çevre (GÇ) interaksiyonları çeşitli analiz yöntemleriyle değerlendirilmiştir. Araştırmada 15 adet genotip kullanılmıştır. Denemeler tesadüf blokları deneme desenine göre üç tekerrürlü olarak kurulmuştur. Genotiplerin tane verimi yönünden stabilitelerini belirlemek amacıyla $S^{(1)}$, $S^{(2)}$, $S^{(3)}$, $S^{(6)}$, $NP^{(1)}$, $NP^{(2)}$, $NP^{(3)}$, $NP^{(4)}$, W_i^2, σ^2_i, s^2d_i, b_i, CVi, $\theta_{(i)}$, θ_i, *K*R parametreleri ile GGE biplot analizi kullanılmıştır. Varyans analizi sonuçları, genotipler, çevreler ve GÇ interaksiyonunun tane verimi üzerinde istatistiksel olarak yüksek düzeyde anlamlı ($p<0.01$) etkiler oluşturduğunu ortaya koymuştur. Stabilite analizleri sonucunda G5 genotipi hem yüksek verimi hem de stabil performansıyla öne çıkarken, G10 ve G6 genotipleri de yüksek tane verimi ve geniş adaptasyon yetenekleriyle dikkat çekmiştir. GGE biplot analizi, bu genotiplerin geniş adaptasyon yeteneklerini ve bazı çevrelerin genotip ayrımı açısından daha ayırt edici olduğunu ortaya koymuştur.

Anahtar kelimeler: Keten çeşitleri, stabilite, genotipler, tohum verimi, GGE-biplot

INTRODUCTION

Flax (*Linum usitatissimum* L.) is a significant cultivated species, valued for its fiber and oil, with an extensive historical background. Today, due to its economic and nutritional significance, it is utilized extensively in textiles, food, cosmetics, animal feed, and pharmaceuticals. Flaxseed comprises 35-40 % oil, referred to as linseed oil. Linseed oil is used as a raw material especially in the dye industry due to its quick drying properties

(İncekara, 1979). Recent climatic changes have directly impacted agriculture, necessitating the development of new varieties and a reassessment of the adaptation of existing ones to the environment. Consequently, identifying genotypes capable of producing high and consistent yields across varying environmental circumstances is crucial for sustainable agriculture. Global vegetable oil production is mostly derived from palm, soybean, canola, sunflower, peanut, cottonseed, olive, corn, and coconut oils, with the flax plant having been incorporated into this list in recent years (Kurt, 2002).

In breeding studies, various statistical methods have been developed for the analysis and interpretation of data. These methods are typically classified into two primary categories: parametric and nonparametric studies, based on their approach to assessing GE interactions and the statistical assumptions underlying them (Gauch, 2006).Parametric analyses include regression coefficient (bi) (Finlay and Wilkinson, 1963), variance of deviation from regression (Sdi ^{2}) (Eberhart and Russell, 1966). Wricke's ecovalence stability index (W_i^2) (Wricke, 1962). Shukla's stability variance (σi^2) (Shukla, 1972), coefficient of environmental variation (CV_i) (Francis and Kannenberg, 1978), mean variance (θ_i) (Plaisted and Peterson, 1959). GE variance component $\theta_{(i)}$ (Plaisted, 1960) and yield stability index (YS_i) (Kang, 1988). Parametric statistics are widely used in the evaluation of quantitative traits of economic importance (Akçura et al., 2006; Sözen et al., 2018; Akçura and Turan, 2020). Nonparametric stability analysis methods include $S^{(1)}$ and $S^{(2)}$ statistics developed by Huehn (1990), $S^{(3)}$ and $S^{(6)}$ statistics proposed later by Huehn. The parameters $NP^{(1)}$, $NP^{(2)}$, $NP^{(3)}$ and $NP^{(4)}$ proposed by Thennarasu (1995). KR (Kang's rank-sum) developed by Kang (1988) and "top rank" methods defined by Fox et al. (1990) and the "top rank" methods described by Fox et al. Since these rank-based analyses involve fewer assumptions than parametric methods, they are widely used in trials conducted under different environmental conditions (Sabaghnia et al., 2006).

In nowadays, parametric and non-parametric stability analyses are utilized together to evaluate genotype x environment interactions. These approaches determine the performance of genotypes under various environmental conditions more reliably and increase the accuracy of genotype selection. (Koc, 2021; Goksoy et.al., 2019)

The GGE biplot method is a graphical and easily interpretable technique that assesses genotype and GE interactions in the analysis of data from multi-environmental trials. This method enables a visual comparison of genotype performance and stability. while simultaneously assessing the discrimination and representativeness of settings (Yan and Kang. 2003). GGE biplot analysis is effective in determining which varieties excel in specific conditions. hence identifying high-yielding and stable cultivars (Yan 2001; Bayhan et al., 2022). The GGE biplot method assesses genotype-environment interactions more efficiently than alternative analytical approaches. Unlike other parametric approaches that typically assess genotype stability. GGE biplot method facilitates the identification of genotype adaptation to specific contexts and elucidates the performance variations of genotypes across all experimental settings (Yan and Tinker, 2006).

This study evaluated oilseed flax (*Linum usitatissimum* L.) genotypes cultivated under diverse conditions for grain production and identified genotypes with high and steady yield potential by assessing GE interactions with different statistical approaches. The study aims to discover how environmental factors affect genotype performance and identify genotypes resistant to production year and environment fluctuation.

This study aimed to evaluate the grain yield performance and stability of 15 oilseed flax genotypes under six different environmental conditions in Edirne, Türkiye

MATERIALS AND METHODS

This study assessed the interaction of genotype and environment with grain production in oilseed flax (*Linum usitatissimum* L.) genotypes using classical analysis of variance alongside other parametric and nonparametric approaches. Furthermore, GGE Biplot analysis was utilized for a more thorough and visual explanation of GE interactions. This analysis determined the discriminative capacity of environments concerning genotypes and the stability of genotypes under varying environmental conditions, thereby establishing a scientific foundation for selecting genotypes that can adapt to the ecological conditions of Edirne.

The study utilized 15 genotypes, comprising 9 varieties of domestic and foreign origin, 5 advanced-candidate lines, and 1 population from Turkiye (Table 1). The experiments were sown in 6 environments according to the randomized complete block design with 3 replications. The plots were planned as 1.02 m wide and 6.2 m long, containing 6 plant rows with 17 cm space in between. At harvest, the middle 4 rows with a length of 5 m were harvested. In sowing, 1250 seeds were used per $1m^2$. Nitrogen was applied at the rate of 300 kg urea per hectare in each environment during sowing. Bentazone (2000 g/ha) for broadleaves and Quaizilophop-p-ethyl (1000 g/ha) for narrowleaves were applied in each environment for weed control. Grain yield was expressed in kilograms per hectare, adjusted to 7 % seed moisture content.

Table 1. Flax genotypes used in the study and their origins

No	Genotype	Flower Color	Seed Color	Hybrid / Pedigree	Year of registration	Country of origin
G1	Karakız	Blue	Brown	Registered variety	2020	Türkiye
G2	Beyaz Gelin	White	Brown	Registered variety	2020	Türkiye
G3	Sarı Dane	Pinkish White	Yellow	Registered variety	2021	Türkiye
G4	KVD-2019/5	Blue	Brown	Victory x Dunes TRE-K10-02-411210T	Candidate Line	Türkiye
G5	KVD-2019/12	White	Brown	Diadem x Tsian TRE-K09-01-912110T	Candidate Line	Türkiye
G6	KVD-2019/15	White	Brown	Diadem x Dunes TRE-K09-02-811110T	Candidate Line	Türkiye
G7	Start	Blue	Brown	Registered variety	-	Russia
G8	F7K2019-7	Blue	Brown	Sarı-85 x T.397 TRE-K11-04-211110T	Advanced Line	Türkiye
G9	F7K2019-8	Blue	Brown	Sarı-85 x T.397 TRE-K11-04-211210T	Advanced Line	Türkiye
G10	Milas	Blue	Light Brown	Population	-	Türkiye-Milas
G11	Sarı-85	White	Yellow	Registered variety	-	Türkiye
G12	Glenelg	White	Brown	Registered variety	-	Australia
G13	Culbert 79	Blue	Brown	Registered variety	-	U.S.A.
G14	Adin	Blue	Brown	Registered variety	-	Romania
G15	Windermere	Light Blue	Yellow	Registered variety	-	Canada

Field experiments were conducted in three locations in Edirne Province, Turkey: two in the Karaagaç district and one at the Trakya Agricultural Research Institute (TARI) during the 2023 and 2024 growing seasons. The same locations were used in both years, resulting in six environment combinations (three locations × two years). This research was performed in three distinct locations with varying treatments in Edirne province during 2023 and 2024 growing seasons. Two trials were conducted in the Karaağaç district and one at the headquarters of the Trakya Agricultural Research Institute (TARI). One of the trials at Karaağaç location was conducted under rainfed + supplemental irrigation and the other under rainfed conditions. In the irrigated environment (sandy-loamy soil), irrigation was applied twice, at the beginning of flowering and capsule filling periods, and 12 liters of water per m² (60 liters per plot) was applied in each irrigation. The non-irrigated trial in the same area was left to natural rainfall only. The third experiment was conducted in the TARI experimental field with clay-loamy soil structure without irrigation (Table 2). The soil structure across environments ranged from sandy-loam to clay-loam, with organic matter content being very low in all environments (0.55–1.08%). Soil pH values were neutral (7.09–7.46), ensuring suitability for flax cultivation.

Table 2. Irrigation status and soil properties of the experimental environments

Code	Environment	Irrigation Status	Irrigation period	Total amount of water supplied (liters/plot)	Soil structure	Organic Matter	Soil Ph
E1	Karaagac 2023	Irrigated 2 times	Flowering Start and Capsule Filling period	120	Sandy loam	0.65 (very low)	7.45 (neutral)
E2	Karaagac 2023	rainfed	-	-	Sandy loam	0.63 (very low)	7.46 (neutral)
E3	Institute Land 2023	rainfed	-	-	Clay loam	0.66 (very low)	7.29 (neutral)
E4	Karaagac 2024	irrigated 2 times	Flowering Start and Capsule Filling period	120	Sandy loam	1.08 (low)	7.20 (neutral)
E5	Karaagac 2024	rainfed	-	-	Sandy loam	0.91 (very low)	7.25 (neutral)
E6	Institute Land 2024	rainfed	-	-	Clay loam	0.55 (very low)	7.09 (neutral)

Between 2023 and 2024, notable disparities were noticed regarding temperature, humidity, and precipitation. In 2023, significant precipitation occurred, particularly in April, resulting in higher humidity compared to 2024, with a total of 222.2 mm of rainfall. The season in 2024 commenced favorably in March, then experienced minimal precipitation (12.6 mm) in June. The year 2023 exhibited elevated humidity levels, comparing with 2024., In the year 2024, temperatures were elevated, particularly between April and July (Table 3). The 2024 growing season was characterized by lower precipitation and humidity, especially in June and July, which may have influenced genotype performance and revealed differential stability responses under drought stress.

Table 3. Edirne Province climate data for 2023 and 2024 growing seasons

Months	Precipitation (mm)		Moisture (%)		Temperature °C					
					Min		Max.		Average	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
March	39.8	56.8	81.3	88.7	-4.1	-0.9	22.1	27.2	9.4	10.3
April	84.6	58.8	86.5	73.2	1.4	3.8	22.1	30.6	12.2	16.3
May	39.4	34.0	77.7	75.5	3.3	6.1	30.1	30.6	16.9	17.1
June	35	12.6	68.9	53.7	9.9	14.3	35.5	38.4	22	26.3
July	23.4	13.8	59.5	49.6	18.5	16.1	35.4	41.4	26.7	28.1
Total/Average	222.2	176	74.78	68.14						

In each environment and year, physiological observations and field practices (sowing, maintenance, harvesting) were carried out according to standard techniques. Sowing was carried out in March-April and harvesting was carried out in July according to the physiological maturity of the genotypes. The grain yield was determined by converting the total seed quantity harvested from each plot into kilograms per hectare. The acquired data were subjected to analysis of variance, and the statistical significant levels of genotype, environment, and GE interactions were ascertained. R-based STABILITYSOFT software developed by Pour-Aboughadareh et al. (2019) was-utilized for stability analysis of genotypes in terms of grain yield. This software allows the calculation of different stability parameters in an online environment and provides significant convenience in the analysis process (https://manzik.com/stabilitysoft/). In this context; Stability statistics developed by Nassar and Huehn (1987) and Huehn (1990), Thennarasu's (1995) analysis, Wricke's (1962) ecovariance index, Shukla's (1972) stability variance, Eberhart and Russell's (1966) mean squared deviations from regression. Finlay and Wilkinson's (1963) regression coefficient. Francis and Kannenberg's (1978) environmental coefficient of variation. Plaisted's (1960) GE variance component, Plaisted and Peterson's (1959) variance component and Kang's (1988) rank sum method were utilized.

To achieve a robust assessment of genotype stability, both parametric (e.g., Shukla's variance, Eberhart–Russell model) and nonparametric (e.g., Nassar and Huehn's statistics, Kang's rank-sum) methods were employed. This combination allows for evaluating stability under diverse assumptions of data distribution and interaction structure.

In order to visually examine the genotype stability, GGE biplot analysis was performed based on mean data across six environments using the Genstat 14th Edition software (Copyright 2011. VSN International Ltd.).

RESULTS AND DISCUSSION

The GE interaction on the grain production of flax genotypes cultivated under varying environmental conditions was assessed, and the genotypes responses to environmental variability were studied. The variance analysis results of the study conducted with 15 spring-planted flax genotypes across 6 environments over 2 years-2 in the Karaagac region (irrigated and dry) and 1 at the Institute headquarters under 3 distinct environmental conditions during the 2023 and 2024 growing seasons—are presented in Table 4.The interaction of environment, genotype, and GE of grain yield were statistically significant at the $p<0.01$ probability level (Table 4). "F" value for the environment indicates a high variation ($F = 14.63$) This suggests that genotype performance is strongly influenced by environment. Grain yield differences between genotypes were also significant ($F=30.66$). This reveals that the studied genotypes had significant yield variability due to their genetic structure. Kroonenberg (1995) and Yan & Kang (2003) noted that GM interaction affects agronomic yield characteristics, making multiple environment trials essential for genotype evaluations. The extremely significant GE interaction shows that genotypes respond differentially to environments and that environmental variability impacts genotype yield. It is vital for genotypes to have high yield potential and be able to retain it under diverse environmental circumstances.

Table 4. Analysis of variance results of genotype x environment interaction for grain yield (kg/ha) genotypes

Source of Variation	Degrees of freedom	Sum of Squares	Mean Squares	F Value
Environment (E)	5	66825.5	13365.1	14.6346**
Replications (Environment)	12	10959.1	913.255	14.1428**
Genotype (G)	14	27718.6	1979.9	30.6611**
Environment*Genotype (ExG)	70	19892	284.171	4.4007**
Error2	168	10848.39	64.57	
Total	269	136243.53		

Table 4 presents grain yield values (kg/ha) together with overall averages. The analysis of average grain yield across the genotypes revealed that genotype G5 had the highest average yield at 754.1 kg/ha. The G10 genotype (743.1 kg/ha) and G6 genotype (741.2 kg/ha) followed this value, respectively. The genotypes with the lowest average grain production were G15 (451.3 kg/ha), G3 (471.6 kg/ha), and G8 (476.5 kg/ha).

The analysis of average grain yield across environments revealed the highest value under E4 conditions, with 955 kg/ha. The minimum yield was recorded under E2 conditions (472.3 kg/ha). This indicates that environmental variables, particularly irrigation, significantly influence grain yield. Table 5 reveals that the genotypes exhibit varying reactions to the environments in the GE interaction analysis. For instance, G5 demonstrated elevated yield across all three conditions, exhibiting both stability and high productivity. G8 produced a minimal yield of 179.1 kg/ha under E2 conditions, whereas it yielded 894.1 kg/ha at E4 conditions. This case demonstrated that genotype G8 produced multivariate outcomes across several contexts and exhibited great sensitivity to environmental factors, indicating instability. While G13 (Culbert 79) demonstrated a good yield in the E6 environment, it garnered attention due to its poor yield of 461.2 kg/ha in the E3 environment. Genotypes G5, G6, and G10 exhibited superior yield and a more consistent performance across settings.

In plant breeding, it is crucial that genotypes possess not just high yield potential but also demonstrate consistent performance across varying environmental circumstances. Consequently, stability analyses are crucial for assessing the response of genotypes to environmental variability. This study's extensive stability assessments facilitated a thorough assessment of the genotypes regarding yield and stability (Table 6). According to Wricke (1962), genotype G1 showed the most stable performance against environmental changes; however, this genotype had low grain yield. On the other hand, genotype G5 was noteworthy for both high yield and stable performance. When the stability variance (σ^2_i) as defined by Shukla (1972) is analyzed. G1 genotype again stands out as the most stable genotype, while G5 is considered as a preferable genotype with both high yield and low variance value. According to Eberhart and Russell (1966) model, G5 was determined as the most suitable genotype with its high yield and stability. According to the analysis of Finlay and Wilkinson (1963) based on regression coefficient, genotype G5 showed superior performance especially in favorable environments, while genotype G10 was found more successful in terms of general adaptability. According to the CV % based evaluation proposed by Francis and Kannenberg (1978), G10, G7 and G6 genotypes were among the prominent genotypes in terms of both high yield and stable performance (Table 6).

The GE variance component θ(i) is a modified measure of the stability parameter. Genotypes with larger values are considered more stable (Plaisted, 1960). In this study, the most stable genotypes according to θ(i) parameter were determined as G1, G5 and G3. However, in the trials conducted under different environmental conditions, not only the stability of the genotypes but also the stability and grain yield averages together give better results. In this context, although genotype G1 has high stability, its grain yield is low; on the other hand, genotype G5 stands out as the most suitable genotype due to both high yield and high stability (Table 6). The mean variance component (θi) statistic developed by Plaisted and Peterson (1959) includes the mean variances estimated for all combinations of common genotypes. In the analysis based on this parameter, G1, G5 and G3 genotypes were determined as the most stable genotypes. Here again, although G1 genotype was the most stable. it was limited with low yield level, while G5 showed a superior performance due to both high yield and low θi value. According to Nassar and Huehn (1987) and Huehn (1990) parameters, G5 was the most stable and reliable genotype. It is also a productive and environmentally compatible genotype because of its high yield**.** According to Thennarasu (1995), G5 was the most stable genotype with both high yield and stability. G1, G4 and

G6 are also notable stable genotypes**.** According to Kang's rank sum (KR) parameter (Kang. 1988). G5. G6 and G7 are the most suitable genotypes because they are both high yielding and stable.

Table 5. Average grain yield values (kg/ha) of different flax genotypes for genotype. environment and genotype x environment interaction

Genotype Number	Genotypes	2023			2024			Genotype Mean
		E1	E2	E3	E4	E5	E6	
G1	Karakiz	489.0	446.5	502.1	883.8	527.0	483.5	555.3e
G2	Beyaz Gelin	563.5	501.2	483.5	854.9	546.6	581.9	588.6e
G3	Sari Dane	383.5	342.6	357.4	808.8	573.5	363.7	471.6f
G4	KVD-2019/5	625.3	554.1	675.0	952.9	751.5	438.0	666.1cd
G5	KVD-2019/12	651.8	595.6	764.7	1144.1	777.0	591.1	754.1a
G6	KVD-2019/15	769.1	617.6	754.1	1104.9	703.0	498.4	741.2ab
G7	Start	651.5	491.5	711.5	955.4	767.2	699.8	712.8abc
G8	F7K2019-7	397.4	179.1	462.9	894.1	527.8	397.5	476.5f
G9	F7K2019-8	532.4	231.5	719.7	972.1	517.2	578.3	591.8e
G10	Milas	732.2	479.4	694.4	1024.5	908.3	628.6	743.1ab
G11	Sari-85	612.4	393.5	560.6	693.6	531.9	494.3	547.7e
G12	Glenelg	807.6	522.6	501.5	1024.5	552.4	530.9	656.6d
G13	Culbert 79	767.1	636.8	461.2	1215.2	588.7	507.1	696.0bcd
G14	Adin	622.9	535.0	550.3	1171.6	747.6	566.1	698.9bcd
G15	Windermere	432.6	557.9	340.6	624.5	424.0	328.4	451.3f
Averages		602.0bc	472.3e	569.3c	955.0a	629.6b	512.5d	

Parametric and nonparametric analysis indicate that while the most stable genotype was G3, its yield fell below the average. Genotype G5 is the best appropriate for high yield and stability criterion among the genotypes. Genotypes G6 and G10 need assessment regarding their specific and broad adaptability potential. The previously mentioned parametric and non-parametric stability metrics allow for the assessment of genotypes based on their stability across various experimental contexts; nonetheless, they exhibit shortcomings in the specific evaluation of individual environments. Therefore, GGE biplot analysis was used to visually evaluate the specific adaptation of genotypes to the experimental environments in terms of grain yield.

The polygon biplot generated by the GGE biplot analysis approach for the comparative assessment of genotype performance across various settings for grain production is illustrated in Figure 1. This method not only elucidates the degree of genotypic adaptation to certain settings but also facilitates the analysis of the distinctiveness of these environments regarding their capacity to differentiate genotypes. In the study conducted by Kumar and Kumar (2021), the yield responses of flax genotypes to different environments were evaluated by GGE biplot analysis and it was emphasized that GE interaction played an important role in genotype selection and it was reported that LC 2063 and LCP 87 genotypes stood out in terms of both high yield and stability. The results indicate that this analysis method is an effective tool in identifying genotypes that are sensitive to environmental variability. In the biplot plot, the first two principal components (PC1 and PC2) explained most of the total variation (77.47%). Genotypes G5, G10 and G6 showed high performance in terms of yields in the majority of the experimental environments and were located at the corner points of the polygon close to the experimental environments. Genotypes G15, G3 and G8 were located at the other corners of the polygon but far away from the trial environments due to their low performance. This structure indicates that genotype G5 possesses extensive adaptability and demonstrates overall success that is not confined to certain situations. Genotypes G5, G10, and G13 exhibit stability regarding both elevated yield and closeness to PC2. On the other hand, genotypes such as G15 and G9 exhibited low stability due to both low yield and high variation. The GGE biplot analysis applied in this study showed once again that it is an effective tool to evaluate the performance and stability of genotypes under different environmental conditions. The G5, G10, and G6 genotypes exhibited elevated yields across various settings and were positioned near the vertices of the polygon in the biplot graphs, indicating their broad adaptability.

Table 6. Stability parameters of grain yield of different flax genotypes

Genotype	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15
Y	55.53	58.86	47.16	66.61	75.41	74.12	71.28	47.65	59.19	74.31	54.77	65.66	69.6	69.89	45.13
W_i^2	65.25	241.07	177.49	278.93	171.86	280.77	291.27	368.29	967.11	405.42	501.87	539.7	1038.15	342.65	959.57
σ^2_i	7.77	48.35	33.67	57.08	32.37	57.51	59.93	77.7	215.89	86.27	108.53	117.26	232.29	71.79	214.15
s^2d_i	8.15	18.83	25.24	38.83	18.73	37.6	32.09	31.89	130.94	57.9	20.31	75.67	108.81	16.92	63.73
b_i	0.93	0.73	1.02	0.93	1.17	1.11	0.79	1.31	1.18	1.01	0.51	1.08	1.43	1.39	0.41
CVi	29.36	23.05	39.46	26.51	27.49	27.58	21.25	49.5	41.39	26.36	18.71	32.44	39.63	34.94	26.18
$\theta_{(i)}$	100.91	98.02	99.06	97.39	99.16	97.36	97.19	95.92	86.05	95.31	93.72	93.09	84.88	96.34	86.17
θ_i	57.99	76.82	70.01	80.88	69.41	81.08	82.2	90.45	154.61	94.43	104.77	108.82	162.23	87.71	153.81
$S^{(1)}$	1.53	3.27	2.6	3.53	1.53	3.27	3.8	2.13	5.73	3.87	3	3.6	5.67	2.6	4.07
$S^{(2)}$	1.77	8.17	6.17	8.57	1.77	8.17	9.37	3.07	22	10.27	5.9	9.87	22.3	4.97	19.37
$S^{(3)}$	1.83	5.98	9.74	4.85	0.67	3.45	4.32	4.6	15.71	4.53	5.36	5.29	10.62	2.44	30.58
$S^{(6)}$	1.1	1.85	3.05	1.51	0.41	1.13	1.38	2.4	3.43	1.24	2	1.36	2.19	0.92	5.58
$NP^{(1)}$	2	3.83	3	3.17	3.67	3.5	3.83	3.33	4.67	2.83	3.67	3.83	6.33	2.83	3.17
$NP^{(2)}$	0.43	0.39	2.13	0.23	0.44	0.24	0.29	1.76	0.57	0.35	0.82	0.3	0.36	0.52	5.5
$NP^{(3)}$	0.53	0.63	1.22	0.42	0.31	0.37	0.38	1.22	0.73	0.34	0.78	0.49	0.61	0.38	1.32
$NP^{(4)}$	0.32	0.48	0.82	0.4	0.12	0.28	0.35	0.64	0.82	0.34	0.55	0.39	0.54	0.26	1.28
***K*R**	12	14	17	12	3	9	11	22	23	12	23	20	21	13	28

Y: Mean grain yield of genotypes (kg/da). $W_{(i)}{}^{(2)}$: Ecovariance (Wricke, 1962), σ^2_i: Stability variance (Shukla, 1972), s^2d_i: Mean squared deviations from regression (Ebehart and Russel, 1966), b_i: Coefficient of regression (Finlay and Wilkinson, 1963), CVi: Coefficient of variation (Francis and Kennenberg, 1978), θ(i): Variance component (Plaisted, 1960), (θi): Mean variance component (Plaisted and Peterson, 1959), $S^{(1)}$, $S^{(2)}$, $S^{(3)}$ and $S^{(6)}$: Huhn's and Nassar's nonparametric statistics, (Nassar and Huehn, 1987) and (Huehn.1990). $NP^{(1)}$, $NP^{(2)}$, $NP^{(3)}$, $NP^{(4)}$: Thennarasu's nonparametric statistics (Thennarasu, 1995), KR: Kang's rank sum (Kang, 1988).

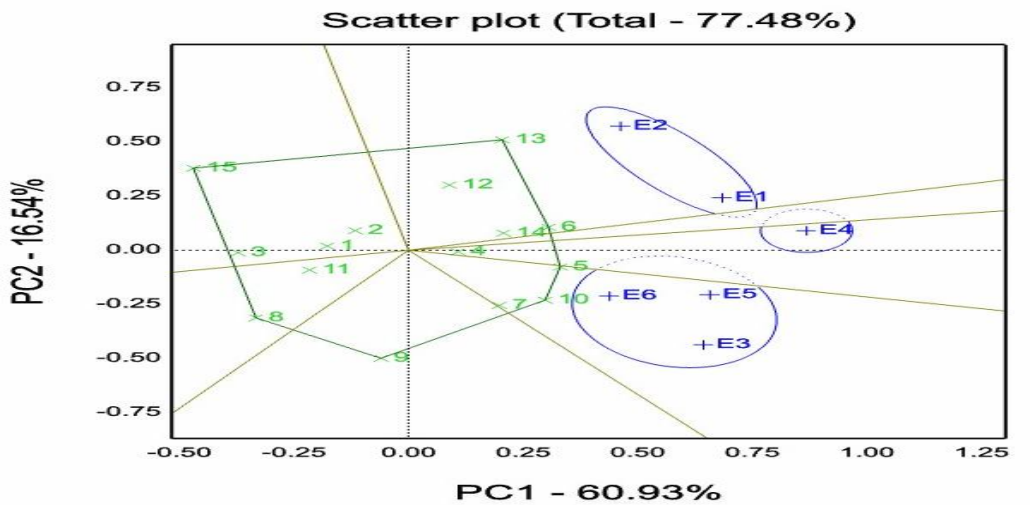

Figure 1. GGE biplot analysis image showing which genotypes are better in which environments in terms of grain yield (kg/da) (1:Karakız, 2:Beyaz Gelin, 3:Sarı Dane, 4:KVD-2019/5, 5: KVD-2019/12, 6:KVD-2019/15, 7:Start, 8:F7K2019-7, 9:F7K2019-8, 10:Milas, 11:Sarı 85, 12: Glenelg, 13:Culbert 79, 14:Adin, 15:Windermere, E1:Karaagac Wet 2023, E2:Karaagac Dry 2023, E3:Institute Center Land 2023, E4: Karaagac Irrigation 2024, E5: Karaagac Rainfall 2024, E6: Institute Center Land 2024)

The results of this study are in agreement with the results of Yan et al. (2000) who showed that GGE biplot analysis is an effective method for evaluating genotypes in terms of both yield and stability. In the aforementioned study, they emphasized that GGE biplot analysis is a powerful tool for evaluating the performance and stability of genotypes in different environments by visualizing GE interaction. Similarly, in the study conducted by Rad et al. (2013) on flax genotypes, it was reported that some genotypes stood out in terms of both high yield and stability using GGE Biplot and AMMI analyses. This result coincides with the fact that genotypes such as G5 and G10 stood out with similar traits in the present study. Furthermore, in a study conducted by Chobe and Ararsa (2018) in the central and southeastern highlands of Ethiopia, it was determined that some flax genotypes showed superior performance in terms of both high yield and stability using GGE Biplot and AMMI analyses. The study revealed that genotypes responded differently to environmental changes and environments differed in their power to discriminate genotypes. In addition, it was found that the effect of GE interaction was approximately two times larger than the effect of genotype. This result indicates that the genotype's response to environmental conditions is more determinant of yield than its genetic potential.

The present study makes a unique contribution to the literature in that it was carried out in Edirne ecological conditions with the data obtained from multi-circle trials in which different environments irrigations and rainfall conditions) were taken into consideration. It provides important contributions to regional adaptation studies, especially in terms of providing original results based on field data for the determination of genotypes suitable for spring flax cultivation in the Thrace Region of Türkiye. The assessment of parametric and non-parametric stability analyses, along with GGE Biplot outputs, facilitated a multidimensional examination of genotype responses to environmental variability, hence enhancing the reliability and comprehensiveness of genotype selection judgments. In this respect, the study has the potential to affect decisions on genotype selection both in terms of agronomic research and breeding programs.

The findings from this study reaffirm the efficacy of GGE Biplot analysis in assessing the interaction between genotype and environment. It was determined that the irrigated conditions of 2024 provided the most significant setting for genetic discrimination. This underscores the important importance of environmental selection in elucidating genetic differences. Purchase et al. (2000) underscored the influence of environmental factors on genotype selection and asserted that environmental sensitivity must be factored into genotype assessments. In conclusion, the results of the present study are in agreement with other studies in the literature and this analysis method plays an important role in genotype selection, especially in breeding programs where environmental interactions are significant.

CONCLUSION

Grain yield of the genotypes showed significant variability among years and environments. Genotypes G5, G10, G6, G13, and G7 exhibited remarkable grain yield and reliable performance across several conditions. Conversely, genotypes G15, G3, and G8 exhibited low yields across numerous settings.

Genotypes G5, G10, and G6 are distinguished as high-yielding and stable choices for grain production in oil flax farming within the Edirne ecological context. In 2024, irrigated conditions were identified as the most

significant environmental factors in differentiating the genotypes. As a result, the E4 environment, where irrigation was applied in 2024, produced the highest seed yield across all genotypes. This clearly demonstrates the decisive effect of irrigation on yield performance. In addition, the mild temperature conditions and adequate humidity observed during the flax growth period—from April to July—may have further supported plant development and contributed positively to yield. These findings indicate that genotype × environment interactions should be evaluated not only in relation to rainfall, but also by considering irrigation practices and prevailing climatic conditions throughout the growing season.

Given the significant degree of genotype-environment interaction, it is crucial to evaluate genotypes across various contexts in breeding operations. The application of multidimensional analyses like GGE Biplot facilitates the simultaneous assessment of yield and stability in genotype selection, hence enhancing decision-making efficacy.

Genotype G5 having high yield and stability may be suggested to farmers due to its reliability against changeable climatic conditions in terms of production.

Genotypes G6 and G10 which have wide adaptability are advantageous for other areas to broaden agricultural extension.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Original Article

Optimization of Sodium Azide Application in Black Cumin (*Nigella sativa* L.) and Determination of Agronomic Characteristics in M_1 Generation

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ABSTRACT

This research represents the first step in enhancing the potential of black cumin seeds for developing new varieties through classical breeding methods. For this purpose, the application conditions of sodium azide, a chemical mutagen, were optimized to produce M_1 seeds. To achieve this optimization, we applied sodium azide mutagen to seeds at various concentrations (1, 2, 3, and 4 mM) and durations (1, 2, 3, and 4 hours) and assessed its impact on germination parameters. A field study involving single plant selections from the mutant and control groups was also conducted to evaluate the agricultural characteristics of plants in the M_1 generation. The results revealed that as the concentration of sodium azide increased, the germination rate, germination rate coefficient, germination rate index, and germination vigor index decreased, while the average germination time increased. The differences in dose significantly affected all variations in germination parameters. The germination rate decreased from 85.6% in the control group to 38.0% with increasing doses. In terms of field performance, significant differences in plant height, first branch height, first capsule height, capsule diameter, and 1000-seed weight were detected between the mutant and control groups of M_1 plants. However, there were no significant differences in the number of branches, capsules per plant, number of seeds in the capsule, or yield per plant. In conclusion, a 3 mM x 2 hour application of sodium azide to seeds effectively induced genetic variation in black cumin, demonstrating its potential for improving black cumin through mutagenesis.

Key words: Mutation breeding, Chemical mutagenesis, *Nigella sativa* L., sodium azide, black cumin

Çörek otu (*Nigella sativa* L.) bitkisinde sodyum azid uygulamasının optimizasyonu ve M_1 generasyonunda tarımsal özelliklerin belirlenmesi

ÖZ

Bu çalışma, çörek otu tohumlarının klasik ıslah yöntemleriyle yeni çeşitlerin geliştirilmesi potansiyelini artırmak için ilk adımı oluşturmaktadır. Bu amaçla, M_1 tohumlarını üretmek için bir kimyasal mutajen olan sodyum azidin uygulanma koşulları optimize edilmiştir. Bu optimizasyonu sağlamak için, tohumlara farklı konsantrasyonlarda (1, 2, 3 ve 4 mM) ve sürelerde (1, 2, 3 ve 4 saat) sodyum azid mutajeni uygulanmış ve çimlenme parametreleri üzerindeki etkisi değerlendirilmiştir. Mutant ve kontrol gruplarından tek bitki seçimlerini içeren bir tarla çalışması da, M_1 jenerasyonundaki bitkilerin tarımsal özelliklerini değerlendirmek için gerçekleştirilmiştir. Sonuçlar, sodyum azid konsantrasyonu arttıkça çimlenme oranı, çimlenme oranı katsayısı, çimlenme oranı indeksi ve çimlenme canlılık indeksinin azaldığını; ortalama çimlenme süresinin ise arttığını ortaya koymuştur. Dozdaki farklılıkların tüm çimlenme parametrelerinde önemli etkileri olduğu saptanmıştır. Çimlenme oranı kontrol grubunda %85.6 iken, artan dozlarla %38.0'a düşmüştür. Tarla performansı açısından M_1 bitkilerinin mutant ve kontrol grupları arasında bitki boyu, ilk dal yüksekliği, ilk kapsül yüksekliği, kapsül çapı ve 1000-tane ağırlığı açısından önemli farklılıklar tespit edilmiştir. Ancak, dal sayısı, bitki başına kapsül sayısı, kapsüldeki tohum sayısı veya bitki başına verim açısından önemli bir farklılık bulunmamıştır. Sonuç olarak,

tohumlara 3 mM x 2 saatlik bir sodyum azid uygulaması, çörek otu bitkilerinde mutagenez yoluyla genetik varyasyonun indüklenmesinde etkili olmuş ve çörek otunun iyileştirilmesinde potansiyelini ortaya koymuştur.

Anahtar kelimeler: Mutasyon ıslahı, Kimyasal mutagenez, *Nigella sativa* L., sodyum azid, çörek otu

INTRODUCTION

Black cumin (*Nigella sativa* L.) is an herbaceous plant belonging to the Ranunculaceae family, with a height ranging from 30 to 70 cm. It has small, black, oval seeds measuring 2-3 mm, capsule-shaped fruits, light blue or white flowers, and a taproot. This plant is an annual herb. The origin of black cumin seeds is thought to be Egypt and the Mediterranean coast (Paarakh, 2010; Hossain et al., 2021). Black cumin has been utilized as a traditional complementary medicine in various civilizations, including Unani, Ayurveda, Arab, Indian, and Chinese traditions. For instance, in Ayurveda, an alternative medical system, black cumin balances Vata (movement energy) and Kapha (structure and lubrication energy) and increases Pitta (metabolism or digestion energy). In the Unani system of alternative medicine, the therapeutic uses of the seeds include relief from stomach issues, laxative effects, gas reduction, combatting coughs, and asthma, and the expulsion of kidney stones (Botnick et al., 2012; Datta et al., 2012; Melnyk et al., 2015; Srinivasan 2018; Hossain et al., 2021; Sommer et al., 2021). Furthermore, numerous studies have reported on the biological effects of black cumin. These studies have indicated that black cumin possesses antimicrobial (Iqbal et al., 2017), antibacterial (Gasong et al., 2017), antifungal (Benazzouz-Smail et al., 2023), antihistaminic (Gholamnezhad et al., 2019), antidiabetic (Rani et al., 2018), anti-inflammatory (Ahmad et al., 2021), anticancer (Butt et al., 2019), anticonvulsant (Noor et al., 2012), antihypertensive (Shahbazi et al., 2022), and antiviral (Basurra et al., 2021) properties.

Black cumin plays a significant role among medicinal and aromatic plants. However, research on yield, yield components, and quality aspects still needs to be completed. Producers commonly use seeds harvested from the previous year's population. Additionally, weed control is a significant challenge due to the lack of suitable herbicides, leading to a reliance on traditional methods such as hoeing and manual weeding. These weeds adversely affect the growth of black cumin plants, resulting in yield and quality losses. Therefore, the development of herbicide-resistant, high-yielding black cumin varieties is crucial.

Genetic variation refers to the differences in DNA sequences among individuals within a population, primarily stemming from mutations. Mutations are sudden heritable changes in the genetic makeup of plants. Mutations can occur spontaneously (naturally) or can be induced artificially. Identifying mutant types can be challenging for breeders, especially when recessive genes are involved and population frequencies are low. Therefore, researchers have attempted to induce artificial mutations through radiation or chemical mutagens (Genç & Özar, 1986). Inducing mutations is one of the methods employed in resistance breeding. The identification of resilient genotypes will facilitate weed control in black cumin farming. Establishing a large breeding population is a prerequisite. Chemical mutations have been effectively utilized as a source of variation in breeding programs, resulting in the development of numerous varieties (Oladosu et al., 2016). Mutation breeding plays a crucial role in plant breeding and assists in creating genetic variation to introduce innovations. Various researchers emphasize that artificial mutation induction through colchicine (Col), ethyl methane sulfonate (EMS), and sodium azide (SA) provides a tool to overcome limitations on variability that can lead to specific improvements in plants without detrimental effects. Sodium azide is a chemical commonly used in mutagenesis studies. An organic metabolite known as β-azidoalanine [N3–CH2–CH(–NH2)–COOH], an amino acid analog, mediates the mutagenicity of sodium azide. This organic metabolite interacts with DNA, inducing AT→GC base pair transitions and transversions (Khan et al., 2009) and chromosomal aberrations (Gruszka et al., 2012). Sodium azide alters the numerous developmental, physiological, and metabolic activities of applied plants. Chemical mutagens induce changes in gene sequences or chromosomes within the plant genome. Compared with chromosomal mutations, mutations in gene sequences have minor effects. Recessive gene mutations are detected in the M_2 generation. However, whether these changes are permanent or modifications can be detected in the M_3 generation through progeny control (Raina et al., 2022).

The primary objective of this research was to optimize the application of sodium azide as a suitable chemical mutagen, the initial step in developing black cumin lines that can be used as a genetic resource in breeding using classical breeding methods. This optimization included determining the appropriate dosage and duration of sodium azide treatment of seeds to obtain the M_1 generation.

MATERIALS AND METHODS

Preparation and Application of a Sodium Azide Solution to Seeds

In our study, we used the 'Çameli' variety of black cumin, which is the only registered variety in Türkiye. Initially, 300 grams of black cumin seeds were soaked in cold tap water for 24 hours. Subsequently, they were immersed in a 1.5% sodium hypochlorite (NaOCl) solution for 15 minutes for sterilization. In the next step, they were rinsed three times with distilled water for sterilization. Considering that the molecular mass of sodium azide is 65.01 g/mol, the following amounts of sodium azide were weighed: 0.065 g for 1 mM, 0.130 g for 2 mM, 0.195 g for 3 mM, and 0.260 g for 4 mM. The weighed sodium azide for each concentration was dissolved in 250 ml of distilled water, adjusted to pH 3, and adjusted to 1 L. Stock solutions were prepared in this manner. These prepared stock solutions were then applied to black cumin seeds for 1, 2, 3, and 4 hours, corresponding to the time intervals that constitute the source of variation. Subsequently, the seeds treated with sodium azide were placed in closed tubes and subjected to magnetic stirring for each duration. The sodium azide-treated seeds were removed from the tubes and air-dried at room temperature. One hundred healthy seeds were selected from each treatment combination, and a control group (pure water) was established to assess their germination-related traits. The performance was evaluated based on the germination rate, germination velocity coefficient, germination velocity index, average germination time, and germination vigor index. The most suitable dose and duration combination (3 mM x 2 hours) for determining germination-related traits was determined. On May 12, 2022, this combination was applied to black cumin seeds to obtain M_1 plants. The treated seeds and control seeds that had not undergone any mutagen treatment were set aside for planting in the field the following day.

Seeds Site and Experiment Description

This study was conducted during the 2022 growing season at the experimental station of the Ataturk University Research and Extension Center in Erzurum, Turkey (39.933° N, 41.237° E, altitude 1789 m above sea level). The experimental region falls under the Dsc climate type, according to the Köppen−Geiger classification (D: severe in winter, s: dry in summer, c: mild cool in summer) (Kottek et al., 2006). Table 1 presents data related to precipitation, temperature, and relative humidity for the experimental site during the vegetation period, including the long-term average (2000-2021) and the data for the year 2022. Climatic data for the study area were collected for specific months, considering the following planting and harvesting times: May (May 13-31), June, July, August, and September (September 01-06).

Table 1. The meteorological data of the experimental area during the long-term (2000–2021) growing periods of black cumin in 2022.

Year	Month					Total/
	May#	June	July	August	September&	Average
			Precipitation (mm)			
Long-term	71.50	49.40	22.30	19.40	4.20	166.80
2022	44.00	65.20	3.10	8.10	0.30	120.70
			Temperature (°C)			
Long-term	9.60	13.70	17.70	15.30	12.80	13.82
2022	10.87	16.70	20.48	23.30	21.66	18.60
			Relative humidity (%)			
Long-term	60.80	55.70	41.50	40.60	47.70	49.26
2022	60.44	60.75	48.55	39.76	38.71	49.64

Calculated from data between 13-31 May;
& Calculated from data between 1-6 September

Based on these values, the total precipitation during the 2022 vegetation period was 120.70 mm, approximately 46.10 mm lower than the long-term average. Although sufficient rainfall was received during May and June, the region transitioned into a dry period starting in July before the black cumin emergence and flowering stages. The average temperature data for 2022 (18.60°C) indicated a significantly higher temperature than the long-term average (13.82°C). Black cumin were observed, and the experimental fields were irrigated during critical periods to mitigate any adverse effects on black cumin. Furthermore, the relative humidity values obtained for the long-term average (49.26%) and for 2022 (49.64%) showed parallel trends. The test soils had a clay-loam texture. The plants were deficient in available phosphorus (8.31 kg ha^{-1}) and total nitrogen (0.827%) but rich in available potassium (145.60 kg ha^{-1}). The experimental area had no salinity problems (0.54%) and

exhibited a slightly alkaline (pH 7.38) structure. The organic matter content (1.31%) and lime content (0.71%) in the trial area were low (Klute, 1986).

The sowing was carried out on May 13, 2022, with a hand planter (Pocta, Model CP-1 SR-1) at a row spacing of 20 cm, using 20 kg of seeds per hectare. Considering the soil moisture content in the designated experimental area and the favorable climate conditions for sowing, a land area of 250 m^2 (25 × 20 m) was allocated for the mutant group, which underwent chemical mutagen treatment. In comparison, 50 m^2 (25 × 2 m) was designated for the control group, which did not receive mutagen treatment. Before sowing in the designated area, 60 kg per hectare of nitrogen (21% AS) and 60 kg per hectare of phosphorous (46% TSP) fertilizers were applied and incorporated into the soil using a disc harrow. Throughout the trial period, three irrigations (on July 1, 2022, July 14, 2022, and July 28, 2022) and three hoeing (on June 6, 2022, June 20, 2022, and July 5, 2022) were carried out.

Plant sampling and harvest

Harvesting began when the capsules started to turn brown and the seeds began to blacken. During harvesting, a 1-meter-wide strip along the edge of the mutant planting area and a 0.5-meter-wide edge of the control planting area were considered edge effects and were not included in the measurements. The remaining plants in the field were harvested together. The harvesting was conducted between September 2, 2022, and September 6, 2022. The capsules were dried with the seeds positioned on top. After the drying process, the plants were threshed to obtain the seeds. Since these seeds were the first generation grown after the mutagen treatment, they were symbolized as "M_1". All plant parameters, including plant height, number of branches, first branch height, capsule diameter, number of capsules per plant, number of seeds per capsule, thousand seed weight, and yield per plant, were calculated based on 100 plants in the randomly selected mutant group and 25 plants in the control group, ensuring that all measurements were taken from the same plant.

Statistical analysis

Following a randomized complete block experimental design, the laboratory study was conducted with five replicates, including the control group. The Duncan multiple comparison test was applied to determine the significance levels of differences between applications. Statistical analyses were performed using JMP Pro 16 software. In the field study, for the determination of agricultural traits in the M_1 generation, 100 plants were selected from the mutant group, and 25 plants were selected from the control group. The following measurements and observations were carried out. The data were subjected to t test analysis using JMP Pro 16 statistical software, and differences were determined using the Duncan multiple comparison test. All observational parameter measurements were conducted on the same plant from the 100 randomly selected plants in the field.

RESULTS AND DISCUSSION

The variance analysis, mean values and multiple comparison results and results for the germination rate, germination rate coefficient, germination rate index, average germination time, and germination vigor index, based on different sodium azide concentrations and durations applied to black cumin seeds, are presented in Table 2. The dose application and dose × duration interaction significantly affected all germination parameters. The effect of duration of application was statistically significant only for the germination vigor index.

As shown in Table 2, the highest germination rate (85.60%) was obtained for the control group. This was followed by 1 mM (60.20%), 2 mM (46.00%), 4 mM (43.80%), and 3 mM (38.00%) sodium azide, respectively. The germination rate decreased with increasing sodium azide concentration, and the control group exhibited a significantly greater germination rate than did the sodium azide treatment group. As a result of the combination of treatments, the highest germination rate (67.20%) was achieved with the application of 1 mM x 3 hours. The lowest germination rate (32.80%) was obtained when 3 mM was applied for 3 hours. The approximately 51.20% decrease in the germination rate between these two combinations indicated the significance of the dose × hour interaction. The germination rate coefficient increased with increasing sodium azide concentration (1, 2, 3, and 4 mM), with values of 11.30, 10.90, 10.75, and 10.99, respectively. In the control group, this value was 12.06. The highest germination rate coefficient was observed for the control group, while the lowest was for the 3 mM sodium azide treatment group. The germination rate indices, depending on increasing sodium azide dose, were determined to be 0.140 (1 mM), 0.109 (2 mM), 0.092 (3 mM), and 0.104 (4 mM), while in the control treatment, the germination rate index was 0.204. The data showed that the highest germination rate index was obtained in the control group, and the lowest was obtained in the 3 mM sodium azide treatment group. The average germination time was between 8.32 and 9.33 days for different sodium azide applications. The earliest

germination occurred in the control group, while the latest germination was observed in the 3 mM sodium azide treatment group. For the other sodium azide treatments, the average germination time was 8.88 days for the 1 mM dose, 9.20 days for the 2 mM dose, and 9.11 days for the 4 mM dose. Considering all factors, the average germination time was 8.97 days. The germination vigor indices of *Nigella sativa* seeds in the 1, 2, 3, and 4 mM sodium azide treatment groups and the control group were 396.10, 286.48, 231.47, 245.99, and 828.96, respectively. The data showed that the highest germination vigor index was obtained in the control group, while the lowest was obtained in the 3 mM treatment group. As shown in Table 2, the germination vigor indices for the 1-, 2-, 3-, and 4-hour sodium azide treatments were 464.81, 420.53, 369.34, and 336.51, respectively, and these differences were found to be statistically significant ($p<0.01$). The germination vigor index decreased linearly with increasing hour applications. Consequently, the lowest germination vigor index was obtained from the 4-hour application, while the highest was detected in the 1-hour application. With increasing sodium azide concentration, the germination rate, germination rate coefficient, germination rate index, and germination vigor index decreased, and the mean germination time increased (Figure 1).

Table 2. Average Values of Germination Parameters in Black Cumin with Different Sodium Azide Concentrations and Durations

Dose (mM)	Duration (sa)	Germination rate	Germination time	Germination rate index	Germination rate coefficient	Germination vigor index
1	1	57.60	8.68	0.134	11.54	517.38
	2	55.20	8.87	0.128	11.32	412.55
	3	67.20	9.55	0.158	10.49	374.76
	4	60.80	8.44	0.142	11.85	279.73
Mean		60.20 b	8.88 b	0.140 b	11.30 b	396.10 b $^{\delta}$
2	1	49.60	9.17	0.116	10.92	426.21
	2	54.40	8.97	0.126	11.18	348.41
	3	40.00	8.91	0.098	11.23	200.75
	4	40.00	9.76	0.096	10.27	170.58
Mean		46.00 c	9.20 ab	0.109 c	10.90 bc	286.48 c
3	1	44.80	9.69	0.106	10.33	319.73
	2	36.80	9.38	0.090	10.71	268.77
	3	32.80	9.09	0.080	11.03	143.20
	4	37.60	9.16	0.090	10.96	194.17
Mean		38.00 d	9.33 a	0.092 d	10.75 c	231.47 c
4	1	43.20	9.31	0.102	10.76	231.79
	2	43.20	9.39	0.104	10.66	244.01
	3	44.80	8.88	0.106	11.26	299.05
	4	44.00	8.87	0.104	11.29	209.14
Mean		43.80 cd	9.11 ab	0.104 cd	10.99 bc	245.99 c
Control		85.60 a	8.32 c	0.204 a	12.06 a	828.96 a
Mean (Duration)	1	56.16	9.03	0.132	11.12	464.81 a
	2	55.04	8.98	0.130	11.19	420.53 ab
	3	54.08	8.95	0.129	11.21	369.34 bc
	4	53.60	8.90	0.127	11.28	336.51 c
General Mean		54.72	8.97	0.130	11.20	397.80
ANOVA		*p > F*				
	df					
Dose (D)	4	**	**	**	**	**
Duration (D)	3	ns ‡	ns	ns	ns	**
D x D	12	*	**	**	**	**

* P < 0.05; ** P < 0.01; ‡ ns, not significant. δ Means within a column not sharing a lowercase letter differ significantly at the P < 0.05 level

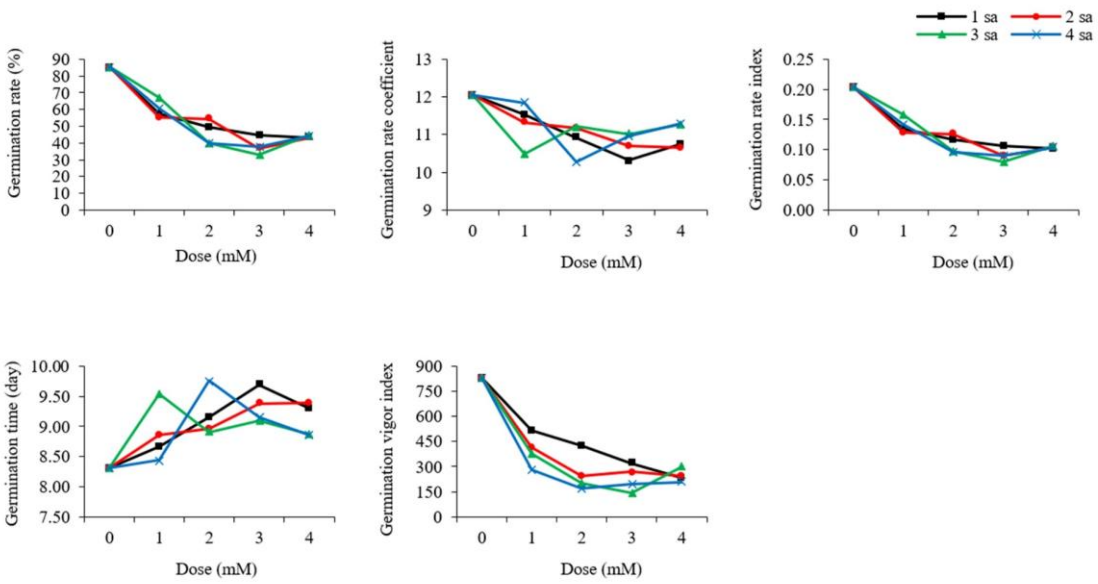

Figure 1. Effects of different sodium azide concentrations and durations on the germination rate, germination rate coefficient, germination rate index, germination vigor index and germination time

The average values and t test results of the yield and yield parameters observed for the M1 generation and control groups of *Nigella sativa* seeds subjected to different concentrations of sodium azide for different durations are presented in Figure 2. During the 2021 vegetative period, differences in plant height, first branch height, first capsule height, capsule diameter, and 1000-seed weight were found to be statistically significant between the control and mutant *Nigella sativa* plants, while the number of branches, number of capsules per plant, number of seeds per capsule, and yield per plant were not significantly different (Figure 2).

The average plant height was determined to be 49.98 cm in the control group and 58.13 cm in the mutant group. The shortest plant height in the control group was 39.5 cm, while in the mutant group, it was 42.5 cm. Conversely, the tallest plant height recorded was 64.5 cm in the control group and 79.5 cm in the mutant group. Overall, the plant heights obtained from the mutant group samples were notably greater than those obtained from the control group samples. As depicted in the scatterplot, clustering was more densely observed in the mutant group (Figure 2).

In the M_1 generation, the difference in the number of branches between the treatment and control plants was not statistically significant. Indeed, the average number of branches for the mutant and control groups was 5.14 and 5.25, respectively, with similar results. In the M_1 generation, the initial height of black cumin was greater than that in the control plants. According to the research results, the first capsule height of the control group varied between 26.2 cm and 47.2 cm, with an average first capsule height of 36.6 cm. The average capsule diameter for the control group was 9.9 mm, while in the mutant group, it was 7.6 mm. When examining the outliers, the lowest capsule diameter measured in the control group was 8.0 mm, whereas in the mutant group, it was 3.4 mm. The greatest capsule diameter was 11.8 mm in the control group and 11.7 mm in the mutant group (Figure 2).

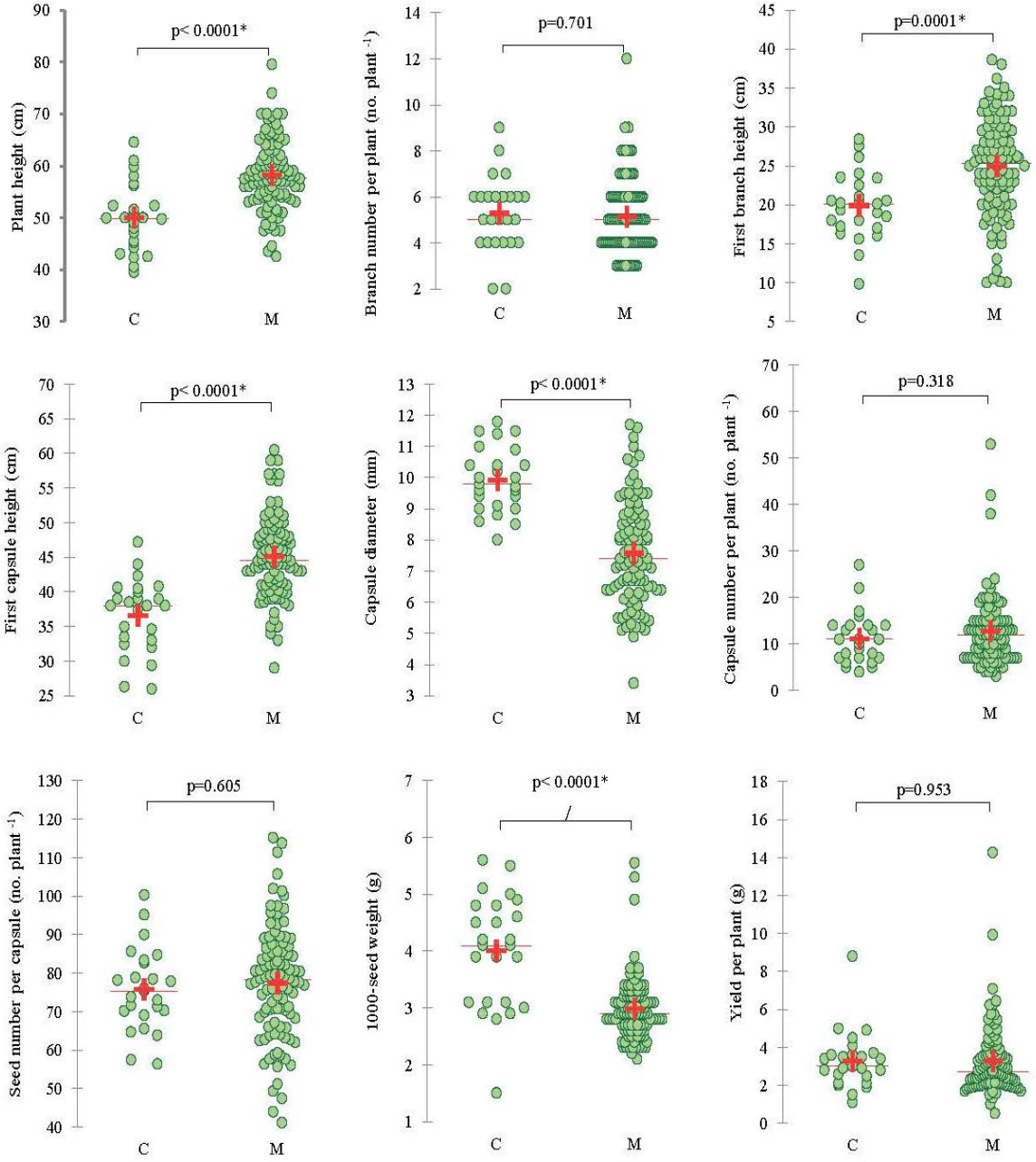

Figure 2. Scatter plot of the yield and yield parameters of the control and mutant black cumin populations.

The control group of plants exhibited larger capsule diameters than did the mutant group, indicating that mutagen treatment reduced the black cumin capsule diameter. The control plants had an average of 11.6 capsules per plant, whereas the mutants had an average of 12.8 capsules per plant. The greatest number of capsules per plant, 53.0, was obtained through mutagen application. The average number of seeds per capsule was 75.7 for the control plants and 77.4 for the mutants, with a wide variation observed in the mutant group, ranging from 42.4 to 115.1 seeds per capsule. As shown in Figure 2, the thousand-seed weight of the plants in the control group ranged from 1.5 g to 5.6 g, with an average of 4 g (Figure 2).

In contrast, the 1000-seed weight of the plants in the mutant group ranged from 2.1 g to 5.5 g, with an average of 2.9 g. Compared to those in the mutant group, the average 1000-seed weight of the plants in the control group significantly increased (Figure 2). The average yield per plant of the mutant plants (3.29 g) was similar to that of the control plants (3.27 g), with a wide range of variation observed within the mutant group. The highest yield per plant in the mutant group was 14.26 g, and the lowest was 0.48 g. An analysis of the

scatterplot revealed clustering within the mutant group, ranging from 0.48 g to 7.09 g, whereas the control group clustered between 1.1 g and 5.0 g (Figure 2).

The mutagenic activity was greater at increased sodium azide doses, leading to more cell mutations, but beyond a certain threshold, germination did not occur. Considering both mutagenic activity and germination parameters, the most suitable sodium azide application dose x duration combination for black cumin plants was determined to be 3 mM x 2 hours. Increased concentrations of sodium azide significantly reduced germination rates. Prabha et al. (2010) reported that the application of sodium azide reduced germination rates in black cumin plants. Similar to our study, the researchers obtained the highest germination rate in the control group plants. Additionally, in a study investigating the effects of physical mutagens on black cumin, Datta et al. (1986) reported that while the germination rate in the control group was 94%, it decreased to as low as 58% with increasing doses, which supports the results obtained in our study. Similarly, in other cultivated plants, such as barley (Cheng & Gao, 1988; Ilbas et al., 2005), chickpea (Khan et al., 2004), sesame (Mensah et al., 2007), canola (Emrani et al., 2011), sunflower (Mostafa et al., 2011), rice (Aurabi et al., 2012), maize (Eze & Dambo, 2015), and cowpea (Raina et al., 2022), increased sodium azide doses and durations resulted in decreased germination rates. Sodium azide induces point mutations at high rates (Jander et al., 2003). Sodium azide, which can induce point mutations, also alters the developmental, physiological, and metabolic activities of plants (Mensah et al., 2007). The observed reductions in germination speed after sodium azide application may be due to point mutations or other genetic damage (Vinithashri et al., 2020). In our study, as the sodium azide dose increased, the average germination time increased, and the germination rate index, germination vigor index, and germination rate coefficient decreased. This phenomenon may result from factors such as hormonal imbalances (Ananthaswamy et al., 1971), the effects of azide anions, which are inhibitors of cytochrome oxidase that inhibit oxidative phosphorylation (Kleinhofs & Sander, 1975), the inhibition of ATP biosynthesis (Cheng & Gao, 1988), the alteration of mitochondrial membrane potential (Zhang, 2000), and changes in enzyme activities (Khan & Goyal, 2009).

The differences in plant height, first branch height, first capsule height, capsule diameter, and thousand-seed weight between the mutant and control groups were significant. In contrast, differences in the number of branches, capsules per plant, seeds per capsule, and yield per plant were not statistically significant. Based on the values obtained, the control group of plants had an average plant height of 58.13 cm, 5.14 branches, a first branch height of 24.88 cm, a first capsule height of 45.06 cm, a capsule diameter of 7.58 mm, 12.76 capsules per plant, 77.4 seeds per capsule, a thousand-seed weight of 2.98 g, and a yield per plant of 3.27 g. In contrast, the mutant group had an average plant height of 49.98 cm, 5.25 branches, a first branch height of 19.86 cm, a first capsule height of 36.58 cm, a capsule diameter of 9.92 mm, 12.16 capsules per plant, 75.7 seeds per capsule, a thousand-seed weight of 4.00 g, and a yield per plant of 3.29 g. The values obtained in the M_1 generation in our study are in line with the results obtained by Ürüşan (2016) and Yıldız (2021), who conducted studies on black cumin cultivation in the region. Moreover, Prabha et al., (2010) found that differences in plant height, number of branches, and thousand-seed weight in the M_1 generation of black cumin plants were statistically significant, indicating wide variation among parameters, similar to our study.

CONCLUSION

In terms of its pharmacological and phytochemical properties, black cumin is a medicinal and aromatic plant with significant importance. Considering its suitability for dry farming rotations, availability of agricultural tools and equipment commonly used for other crops, positive market supply and demand trends, and ease of processing, its inclusion in agricultural patterns is important and necessary. In the future, morphological mutants with superior characteristics will serve as genetic sources for breeding programs. Considering the results obtained, a combination of 3 mM sodium azide treatment for 2 hours can be applied to black cumin seeds to increase genetic diversity. Since full expression of land values is not expected in the M_1 generation, it is important to reevaluate the results with M_2 values. In the subsequent phases of the research, given that the genetic mutations for breeding purposes, such as herbicide resistance and high yield, are likely to be recessive, genetic inheritance studies are aimed at determining the M_2 generation. Additionally, whether these changes are permanent or modified will be assessed in the M_3 generation through progeny control.

Declaration of interests

The authors declare that there are no identifiable conflicts of interest, either financial or personal, that might have influenced the work presented in this paper. This research article was derived from the master dissertation of Hivrun Turanlı.

Author Contributions

Hivrun Turanlı : Conceptualization; data curation; formal analysis; investigation; methodology; software; writing— original draft.
Furkan Çoban : Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; writing— original draft; writing—review and editing.
Kamil Haliloğlu : Conceptualization; data curation; formal analysis; investigation; methodology; software; writing—review and editing.

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Araştırma Makalesi

Trakya Bölgesi Doğal Florasında Belirlenen Önemli Bazı Yabani Fiğ (*Vicia* spp.) Türlerinin Ekolojik Dağılımı ile Verim ve Verim Özelliklerinin Belirlenmesi

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ÖZ

Araştırma Trakya bölgesinde farklı yükselti ve toprak yapısına sahip farklı ekolojik alanlarda dağılım gösteren önemli bazı *Vicia* cinsine ait türlerin belirlenmesi, türlerin tarla koşullarında yetiştirilerek verim ve verim özelliklerinin saptanması amacı ile yürütülmüştür. Bölgede İki yıl boyunca sürdürülen sörvey çalışmaları sonucunda toplanan 23 farklı tür arasında yer alan 6 türe ait 33 genotip, 2 yıl süresince Tekirdağ Namık Kemal Üniversitesi Ziraat Fakültesi Deneme ve Uygulama alanında yetiştirilmiştir. İki yıl boyunca verim ve özellikleri belirlenmiş ve basit istatistiki analiz sonuçları ile Biplot analizi, grafik olarak verilmiştir. Yapılan değerlendirmeler sonucunda en uygun seleksiyon kriterlerinin sap çapı, bin tane ağırlığı ve bitki tohum verimi olduğu saptanmıştır.

Anahtar Kelimeler: Genetik kaynaklar; lokasyon; Biplot analizi; *Vicia* L.**,** *Vicia villosa* Roth., *Vicia pannonica* Crantz.

Determination of Ecological Distrubition and Yieild and Yield Characteristics of Some Importanton Wild Vetch (*Vicia* spp.) Species in The Natural Flora of Thrace Region

ABSTRACT

This research was carried out with the aim of determining some important Vicia species distributed in different ecological areas with different elevation and soil structure in Thrace region and determining the yield and yield characteristics of the species by growing them under field conditions. Thirty-three genotypes belonging to 6 species among 23 different species collected as a result of the surveys carried out in the region for two years were grown in Tekirdağ Namik Kemal University Faculty of Agriculture Experiment and Application area for two years. Yield and characteristics were determined for two years and the results of simple statistical analyses and Biplot analysis were given graphically. As a result of Biplot analysis, it was determined that the most suitable selection criteria were number of days to fruit ripening, number of days to harvest and plant seed yield.

Key words: Genetic resources; location; Biplot analysis; *Vicia* L., *Vicia villosa* Roth., *Vicia pannonica* Crantz.

GİRİŞ

Türkiye ılıman iklim koşullarına adapte olmuş çok sayıda baklagil türünün gen merkezidir (Davis ve Plintman, 1970). Yonca (*Medicago* sp.), üçgül (*Trifolium* sp.) ve fiğ türleri (*Vicia* sp.) Türkiye'nin orta ve güney

bölgelerinde doğal florada yaygın olarak bulunmaktadır (Bennet ve Bejar, 1998). Bunlar arasında yer alan bazı fiğ türleri kaba yem üretiminde ve toprak ıslahında kullanılmaktadır.

Fiğ türleri serin mevsim baklagil yem bitkileridir. Dünya genelinde 190, Türkiye'de ise 64 adet farklı fiğ türü bulunmaktadır (Erik ve Tarıkahya, 2004; ILDIS, 1999). ICARDA tarafından toplanan fiğ cinsine ait 5500 alt tür olduğu bilinmektedir. Çok sayıda araştırmaya konu olan fiğ türleri, coğrafi olarak Akdeniz bölge ülkelerinde dağılıma sahiptir (Kupicha, 1981). Avcılıkla yaşamını sürdüren insanların yerleşik yaşama geçmelerinden sonra bakla (*V. faba* L.), adi fiğ (*V. sativa* L.), koca fiğ (*V. narbonensis* L.), burçak (*V. ervilla*) ve tüylü fiğ (*V. villosa* Roth.) gibi türleri yetiştirmişlerdir (Gil ve Cubero, 1993). Türkiye'nin yarı kurak bölgeleri ile Akdeniz bölge ülkelerinde kıraç koşullarda yetiştirilen adi fiğin (ICARDA, 1998), büyük olasılıkla Güney Avrupa veya Güneybatı Asya kökenli olduğu bilinmektedir (Maxted, 1995). Tek yıllık özelliğe sahip adi fiğ, Macar fiği ve tüylü fiğin yabani türleri Sırbistan ve Karadağ doğal florasında yoğun olarak bulunmaktadır (Miladinovic, 2001). Macar fiği ise Doğu Akdeniz florasında bulunan ve tarımı yapılan sert kışlara toleranslı önemli bir türdür (Orak, 2000). Düşük sıcaklıklara en fazla toleransa sahip tüylü fiğ ise yabancı ot yoğunluğunu kontrol eden, toprak verimliliğini olumlu yönde etkileyen sarılıcı özelliğe sahip bir türdür (Hartwing ve Ammon, 2002). Ükemizde ekim alanı azalmış olan burçak Asya'nın birçok ülkesinde ve Balkanlar'da tane yem üretiminde kullanılmaktadır.

Akdeniz iklimine sahip ılıman koşullarda genelde kışlık olarak ekilen fiğ türleri ot ve silaj üretimi ile yeşil gübre amacı ile de yetiştirilmektedir (Açıkgöz, 2001). Geleneksel tarımda kaba yem olarak; ayrıca saman ve anız artıkları hayvan beslemede kullanılmaktadır.Trakya bölgesi kuzeyde Karadeniz, güneyde Marmara Denizi ile sınırlanan; Anadolu'dan Çanakkale ve İstanbul boğazları ile ayrılan bir yarımadadır. Türkiye'nin Avrupa kısmını temsil etmektedir. Türkiye'nin Kuzey batı, Avrupa kısmının büyük bir bölümüne sahip Trakya bölgesi, organik madde içeriği düşük, farklı düzeylerde killi ve kumlu-killi topraklara sahiptir. Bölgede önemli iki dağ silsilesi bulunmaktadır. Istranca dağları bölgenin kuzeyinde, Ganos dağları ise güneyinde yer almaktadır. Istranca Dağları, Bulgaristan sınırından İstanbul'a kadar Kuzey Batı - Güneydoğu yönünde Trakya bölgesi boyunca yer almaktadır. Bölgenin deniz seviyesinden yüksekliği ortalama 180 metredir.

Tekirdağ, Edirne ve Kırklareli illerinde yaşayanların temel geçim kaynağı tarımdır. Bölgede çayır mera alanlarının sınırlı, tarla tarımı içinde yer alan yembitkileri ekim alanın yetersiz olması nedeni ile doğal mera ve çayırlar aşırı otlatılmakta, dolayısı ile zengin bitkisel gen kaynakları olumsuz etkilenmektedir (Nizam ve ark., 2022).

Yörede, geleneksel yerel çeşitler ve yabani akrabalar tarafından temsil edilen bitkilerin genetik çeşitliliği son yıllarda yok olma tehdidi altındadır. Dünya genelinde son bin yılda, toplam bitki türü sayısının %10'u geri gelmeyecek şekilde yok olmuştur (Raven, 2000). Bitki çeşitliliğinin korunması, tanınması, koleksiyon oluşturulması, adaptasyon çalışmalarının devamlılığı ve ıslah materyali olarak değerlendirilmesi ile mümkündür. Bu anlamda; Trakya bölgesi ılıman iklim koşullarına adapte olmuş bitkilerin gen merkezi olarak bitki ıslahında önemli kaynak konumundadır.

Bitki ıslahında başarı, ekotiplerin oluşturduğu popülasyonu mümkün olduğu kadar geniş tutmakla mümkün olabilir. Öncelik, popülasyonda yeralan türlerin incelenmesi ve gelecek vaat eden ekotiplerin belirlenmesine verilmelidir. Tek yıllık fiğ türlerinden adi fiğ, koca fiğ, eşek fiği (*V. angustifolia)* , boz fiğ (*V. hirsuta*), tüylü fiğ ve kaba tüylü fiğ yabani floranın tipik bitkileri olup boz fiğ ve eşek fiği yem bitkisi olarak fazla değeri olmayan istilacılar grubunda yer almaktadır. Adi fiğ, koca fiğ, Macar fiği ve tüylü fiğ zaman zaman tane ve kaba yem üretimi için yetiştirilen baklagillerdir.

Yöre ekosisteminde yeralan *V. sativa* ssp. nigra alt türüne ait ekotipler genellikle Ege ve Akdeniz kıyı şeridi ile Anadolu iç kesimlerde dağlık alanlarda bulunmaktadır. Adi fiğ (*V. sativa* ssp. sativa L.)'in *V. sativa* ssp. nigra aynı lokalitelerde bulunması zor olan türlerdir. Ülkemizin güneybatı bölgesi tüylü fiğin ekolojik isteklerinin karşılandığı doğal yayılım alanlarıdır. Farklı toprak isteğine sahip melez fiğ (*V. hybrida*) ise doğal meralar ve tarla sınırlarında pH değeri 8 ila 10 olan kumlu veya kumlu-tınlı topraklarda bulunmaktadır (Bennet ve ark., 1998).

Ortalama 450-550 mm yıllık yağış rejimine sahip, yağışların yıl içinde dağılımının düzensiz olduğu Trakya kuru tarım sistemine sahip bir bölgedir. Kapladığı alan olarak ülkemizin 1/36'ne sahiptir. Özellikle Kırklareli bölgesinde yeralan Yıldız Dağlarının etekleri çok sayıda bitki türüne ev sahipliği yapmaktadır. Özellikle fiğ türlerinin yoğunluğu dikkati çekmektedir. Bu araştırmada, bölgeye yayılmış mevcut fiğ türlerinin dağılımının belirlenmesi yanında, tarla koşullarında yetiştirerek fenolojik ve morfolojik özellikleri ile tohum verimlerinin tespit edilmesi amaçlanmıştır.

MATERYAL ve METOT

Fiğ Türlerinin Toplanması

Trakya bölgesi doğal florasında sörvey çalışmaları ile belirlenen lokasyonlardan fiğ türlerine ait bitki ve tohum örneklerini toplamak amacı ile Mart ayından itibaren Temmuz ayı sonuna kadar (2014-2015) iki yıl boyunca fiğ türleri 211 adet farklı lokasyondan toplanmıştır. Çalışma alanı kuzeyde 41°09 7.80 ile doğuda 27°21 59.99 arasında yer almaktadır. Trakya Bölgesi topografik, iklimsel ve biyoçeşitlilik olarak heterojen yapıya sahiptir. Bölgenin güney kıyılarına yakın bölümü Akdeniz iklimi özelliklerini gösteren ılıman, yağışlı kışlar ve sıcak, kurak yazlarla karakterize edilmektedir. Kuraklık dönemi genellikle Mayıs ayından Eylül ayına kadar uzanır. Karadeniz kıyısına doğru ya da bölgenin kuzeyine doğru koşullar daha nemli ve serin olmaktadır. Trakya'nın doğu kesiminde yağışlar genellikle kış aylarında yoğunlaşmakta olup yıllık ortalama 589,27 mm'dir (Tekirdağ, Edirne ve Kırklareli illerinin uzun yıllar ortalama yağışları; Anonim, 2021).

Fiğ türlerinin toplandığı lokasyonlar bölgenin tamamını temsil edecek şekilde belirlenmiş ve türlerin toplandığı alanlar, ayrıntılı olarak kaydedilmiştir. Türlerin toplandığı alan bilgileri; enlem, boylam (Magellan GPS ünitesi kullanılarak), rakım bilgileri alınmıştır. Fiğ türlerine ait bilgiler takson, çiçek rengi, popülasyon tipi, yoğunluk, toplama sırasında türlerin çiçek açıp açmadığı ve/veya meyve verip vermediği ile ilgili bilgiler kaydedilmiştir. Sörvey çalışmaları sırasında kullanılan taksonomik anahtarlar için Davis ve Plitmann (1970), Zohary ve Heller (1984) ve Maxted (1995) kaynaklarından yararlanılmıştır. Bitki teşhisleri Trakya Üniversitesi Fen Fakültesi Biyoloji Bölümünde yapılmıştır.

Trakya bölgesinde 5 il (İstanbul, Tekirdağ, Kırklareli Çanakkale ve Edirne) , 29 ilçe (Şekil 1) ve sörvey çalışmalarının ilk yılında (2014 yılı) 111 farklı lokalite (Çizelge 1, Şekil 2), ikinci yılında (2015 yılı) 100 farklı lokalite (Şekil 2, Çizelge 2) olmak üzere toplam 211 alan ziyaret edilerek fiğ türleri toplanmıştır.

Şekil 1. Durak yerlerinin seçildiği ilçeler/merkez ilçeler

İlk yıl toplanan fiğ örnekleri Şekil 2'de olduğu gibi kırmızı nokta ile işaretlenmiş ve tür bazında sınıflandırılmıştır. Türler arasında sörvey çalışmaları esnasında iyi gelişme gösteren genotipler tarla denemeleri için materyal olarak kullanılmıştır. Aynı şekilde ikinci yıl sörvey çalışmalarında da toplanan farklı türlere ait tohumlar materyal olarak kullanılmış ve Şekil 2'de görüleceği üzere beyaz noktalı olarak işaretlenmiştir.

Şekil 2. Çalışma yapılan lokaliteler

Sörvey çalışmalarının 1. yılında (2014 yılı) fiğ türlerinin toplandığı lokalitelere ait bölge, mevki, yükselik ve koordinatlar Çizelge 1'de sunulmuştur.

Çizelge 1. Fiğ türlerinin toplandığı lokalitelere ait bölge mevki ve koordinatlar (2014 yılı)

No	Bölge	Mevki	Koordinat (kuzey)	Koordinat (doğu)	Yükseklik (m)
1	Koru dağları	Karakol mevkii	40°42'9.60"	26°45'31.56"	350
2	Gelibolu	Ecabat yolu tersane yanı	40°18'58.80"	26°34'17.46"	6
3	Gelibolu	Ecabat yolu tersane yanı	40°19'4.44"	26°34'16.68"	13
4	Gelibolu	Ecabat yolu tersane yanı	40°19'2.34"	26°34'5.52"	64
5	Kumbağ	Kumbağ tepesi	40°51'11.82"	27°27'12.96"	126
6	Kumbağ	Arıcılık karşısı	40°51'13.50"	27°27'11.10"	126
7	Kumbağ	Kumbağ tepesi	40°51'10.26"	27°27'8.28"	134
8	Kumbağ	Kumbağ tepesi	40°51'5.22"	27°27'4.80"	149
9	Kumbağ	Orman açması	40°51'3.84"	27°26'14.76"	126
10	Uçmakdere	Köy çıkışı çeşme üstü	40°47'52.68"	27°21'48.00"	117
11	Uçmakdere	Köy içinden çınardan yukarı	40°48'3.12"	27°21'42.96"	126

		dere ke			
12	M.Ereğlisi	Seymen yolu 5. km yol kenarı	40°59'34.92"	27°57'14.10"	9
13	M.Ereğlisi	Seymen yolu , omurga çiftliği	41° 2'7.08"	27°57'12.84"	25
14	Çorlu	Havaalanı kavşağı	41° 6'41.10"	27°55'30.00"	103
15	Silivri	Semizkum bölgesi pazaryeri	41° 4'33.36"	28° 9'9.78"	26
16	Çatalca	Saray yolu çıkışı , Yatsan mobilya ya	41° 9'23.64"	28°27'16.38"	61
17	Çatalca	Kestaneli köyü	41°13'17.64"	28°29'49.92"	35
18	Çatalca	Kestaneli köyü	41°13'17.46"	28°29'52.62"	36
19	Çatalca	Çanakça köyü , köy çıkışı	41°15'16.98"	28°29'27.42"	77
20	Çatalca	Çanakça köyü , köy çıkışı	41°18'8.46"	28°27'39.90"	138
21	Çatalca	Çanakça köyü , köy çıkışı	41°18'8.46"	28°27'41.46"	136
22	Çatalca	Çanakça köyü , köy çıkışı	41°21'11.52"	28°27'13.80"	136
23	Çatalca	Çanakça köyü , köy çıkışı	41°21'14.64"	28°27'8.46"	33
24	Çatalca	Karamandere yolu	41°22'16.92"	28°17'18.12"	137
25	Köseilyas	Çiftlik önü yolu	41° 0'7.74"	27°33'22.50"	83
26	Köseilyas	Çiftlik önü yolu	40°59'31.50"	27°32'25.92"	120
27	Köseilyas	Kayı yolu	41° 0'27.06"	27°33'0.30"	91
28	Silivri	Büyükkılıçlı köy çıkışı mera karşısı	41°10'33.18"	28°11'12.66"	136
29	Silivri	Büyükkılıçlı köy çıkışı mera karşısı	41°11'12.66"	28°10'41.94"	197
30	Silivri	Alipaşa-Karamandere yolu , Beyciler	41°13'47.46"	28° 9'51.18"	236
31	Silivri	Danamandıra köyü	41°17'51.42"	28°14'15.72"	158
32	Silivri	Danamandıra Karacaköy çıkışı	41°19'36.54"	28°15'7.92"	194
33	Silivri	Binkılıç köyü, lise karşısı	41°24'45.18"	28°10'43.50"	171
34	Silivri	Binkılıç köyü çıkışı	41°24'48.00"	28°10'13.86"	163
35	Saray	Çatalca yolu girişi	41°26'43.44"	27°56'53.52"	168
36	Yağcı	Yağcı merası sağ taraf	41° 0'49.08"	27°25'54.00"	271
37	Banarlı	Hacıköy taş ocakları yolu girişi çeşm	41° 2'2.88"	27°22'8.16"	144
38	Yörükler köyü	Köy girişi mera	41° 6'52.44"	27°14'30.90"	101
39	Hayrabolu	Malkara yolu 4. km	41°10'8.28"	27° 3'17.82"	76
40	Malkara	Kozyörük merası	41° 3'45.36"	26°58'25.62"	138
41	Malkara	Kozyörük piknik alanı	40°59'41.94"	26°56'27.66"	168
42	Malkara	Yenice köyü çıkışı çamlık	40°54'44.82"	27° 8'16.56"	167
43	Çorlu	Belediye Piknik Alanı	41°14'27.06"	27°41'53.28"	105
44	Şarköy	Sağlamtaş çıkışı çeşme arkası	40°41'35.76"	27°17'29.70"	11
45	Şarköy	Sağlamtaş çıkışı çeşme arkası	40°38'42.11"	27° 5'38.97"	79
46	Şarköy	Sağlamtaş çıkışı çeşme arkası	40°47'8.25"	27° 6'43.58"	160
47	Tatarköy	Lüleburgaz çıkışındaki mera	41°28'34.78"	27°20'35.91"	107
48	İnanlı köyü	Mera biçilen yer	41°10'59.60"	27°27'49.38"	84
49	Gökçetepe	Dokuzdere göleti	40°44'22.08"	26°41'7.02"	83
50	Gökçetepe	Mesire alanı	40°38'11.82"	26°36'6.36"	29
51	Kırklareli	Koyunbaba köyü	41°43'21.54"	27° 6'49.80"	121
52	Babaeski	Müsellim-Kumrular arası	41°28'53.94"	27°12'54.48"	89
53	Babaeski	Çeşmekolu Göleti yakını	41°32'20.22"	27°15'40.20"	141
54	Saçlımüsellim	Saçlımüsellim-Elçili arası	41°25'48.12"	26°37'54.06"	41
55	Çakmakköy	Köy yakını	41°22'5.64"	26°40'4.32"	53
56	Lalapaşa	Hanlıyenice	41°52'39.06"	26°41'0.90"	248
57	Hamzabeyli		41°57'25.44"	26°40'26.82"	455
58	Kırklareli	Kızılcıkdere-Üsküpdere arası orman	41°42'12.60"	27°20'33.60"	212
59	Kıklareli	Beypınar yakınları dağlık alan	41°47'43.68"	27°27'20.88"	533

60	Koru Dağları	Karakol mevkii	40°42'16.02"	26°45'52.62"	347
61	Keşan	Büyükdoğanca-Kılıçköy arası orman	40°46'38.28"	26°34'12.54"	31
62	Keşan	Kızkapan köyü yakınları	40°43'34.62"	26°29'17.16"	120
63	Edirne	Tayakadın köyü yakınları	41°32'59.22"	26°40'0.42"	55
64	Meriç	Kavaklı-Karahamza arası	41°15'9.00"	26°31'30.30"	106
65	Meriç	Meriç-Küpdere arası	41°12'27.18"	26°26'39.30"	59
66	Lüleburgaz	Alacaoğlu yakınları	41°18'48.24"	27°19'39.90"	66
67	Lüleburgaz	Alacaoğlu yakınları	41°16'53.22"	27°17'53.94"	77
68	Demirköy	Yenice yukarı ormanlar	41°45'6.72"	27°38'48.24"	666
69	Demirköy	Kurudere yukarı ormanlar	41°46'44.94"	27°34'19.56"	551
70	Süloğlu	Süloğlu baraj göleti yakınları	41°46'54.24"	26°55'24.54"	186
71	Süloğlu	Akardere yolu gölet yakını	41°42'17.76"	26°55'28.08"	155
72	Lalapaşa	Hacıdanişment yolu	41°52'46.38"	26°46'28.86"	291
73	Pehlivanköy	Ömerbey-Sultanşah arası	41°20'38.88"	26°55'34.20"	46
74	Pehlivanköy	Ömerbey-Sultanşah arası	41°15'4.44"	26°52'0.12"	77
75	Pehlivanköy	Gazimehmet-Elmalı arası	41°11'39.78"	26°54'11.28"	180
76	Lalapaşa	Hacıdanişment-Süleymandanişment	41°54'9.24"	26°52'1.38"	405
77	Lalapaşa	Vaysal yakınları	41°56'57.60"	26°55'1.98"	371
78	Lalapaşa	Vaysal-Devetliağaç arası	41°58'15.66"	26°56'32.04"	346
79	Lalapaşa	Vaysal-Devetliağaç arası	41°58'29.28"	26°59'12.42"	409
80	Havsa	Oğulpaşa köyü	41°35'7.34"	26°45'13.68"	87
81	Babaeski	Mutlu köyü	41°30'35.46"	27° 0'6.42"	103
82	Babaeski	Kuzuçardağı köyü	41°32'12.48"	27° 3'46.38"	124
83	Armutveren	Köy yakını yukarı ormanlar	41°53'45.48"	27°30'41.82"	540
84	İğneada		41°52'33.18"	27°57'1.32"	17
85	İğneada		41°53'19.98"	27°59'50.82"	0
86	Demirköy	Hamdibey yolu	41°50'14.40"	27°47'40.68"	214
87	Vize	Çövenli köyü yakınları	41°30'2.70"	27°42'9.42"	177
88	Demirköy	Enez-Hisarlı arası	41°47'43.02"	27°44'13.38"	660
89	Enez	Enez-Hisarlı arası	40°42'24.90"	26°4'4.98"	2
90	Enez	Enez-Hisarlı arası	40°44'2.94"	26°10'10.56"	192
91	Enez	Enez-Hisarlı arası	40°43'32.58"	26°11'21.48"	277
92	Ahmetbey	Ahmetbey Atatürk Cevizliği	41°28'55.80"	27°35'20.00"	143
93	Cevizköy	Cevizköy çıkışı su deposu yanı	41°33'8.50"	27°35'5.50"	241
94	Erenler köyü		41°37'42.40"	27°33'56.90"	262
95	Poyralı köyü	Poyralı-Demirköy yolu	41°39'26.70"	27°36'30.50"	320
96	Yenice köyü	İslambeyli girişi	41°43'17.10''	27°37'46.00"	401
97	Yenice köyü	Sergen çıkışı	41°43'46.00"	27°38'34.10"	469
98	Yenice köyü	Yenice köyü Sergen yolu çayır içi	41°43'13.50"	27°39'19.40"	412
99	Pınarhisar	Pınarhisar-Vize yolu Sergen kavşağı	41°36'56.00"	27°40'11.10"	316
100	Cevizköy	Cevizköy-doğanca çıkışı	41°34'0.60"	27°36'20.20"	220
101	Ballıhoca		41°12'50.80"	27°29'58.60"	79
102	Hayrabolu	Uzunköprü yolu-organize sanayi böl	41°13'13.70"	27° 3'1.70"	115
103	Hayrabolu	Uzunköprü yolu-organize sanayi böl	41°13'17.30"	27° 1'5.40"	177
104	Hayrabolu	Uzunköprü yolu-organize sanayi böl	41°13'43.20"	26°51'42.20"	110
105	hayrabolu	Uzunköprü yolu	41°13'39.50"	26°51'19.50"	112
106	Çakmak köy	Çakmak köyü çıkışı fundalık Yunani	41°23'33.00"	26°39'31.40"	94
107	Elçili köyü		41°27'34.90"	26°37'29.50"	37

108	Sinanlı köyü		41°20'5.40"	27° 8'18.70"	62
109	Haliç köyü	Haliç köyü geçince solda tepelik ala	40°52'6.60"	26°46'37.40"	276
110	Keşan	İpsala çıkışı 5. km toki yol ayrımı pik	40°52'34.40"	26°35'46.50"	64
111	Keşan	İpsala yolu Korucuköy çıkışı ağaçlık	40°52'58.80"	26°30'11.40"	78

Sörvey çalışmalarının 2. yılında (2015 yılı) fiğ türlerinin toplandığı lokalitelere ait bölge, mevki, yükselik ve koordinatlar Çizelge 2'de sunulmuştur.

Çizelge 2. Fiğ türlerinin toplandığı lokalitelere ait bölge mevki ve koordinatlar (2015 yılı)

No	Bölge	Mevki	Koordinat (kuzey)	Koordinat (doğu)	Yükseklik (m)
112	İpsala	Yenikarpuzlu yolu beton satrali yani	40°53'35.80"	26°21'59.70"	25
113	Keşan	Uzunköprü yolu 4. km	40°53'49.00"	26°37'59.60"	77
114	Alıçköy	Köy girişi ağaçlık alan	41° 3'49.10"	26°38'36.50"	144
115	Davutköy	Doluköy yolu	41° 2'22.00"	26°46'14.40"	195
116	Şahin	Malkara çıkışı	41° 0'54.00"	26°50'20.40"	199
117	Yazır	Gölet kenarı	40°54'55.90"	27°24'25.20"	63
118	Naip	Hayri abinin bahçesi	40°52'29.34"	27°24'6.47"	33
119	Avşar	Köy çıkışı	40°53'41.50"	27°21'49.20"	142
120	Avşar	Köy çıkışı	40°54'5.40"	27°21'44.70"	181
121	gelibolu	Ilgardere yolu-üçevler mevkii	40°16'42.40''	26°28'52.00"	36
122	Gelibolu	Tarihi yarımada tuz gölü büyükmeşe	40°17'54.90"	26°16'43.90"	14
123	Gelibolu	Şehitlik Abidesi fransız mezarlığı önü	40° 3'14.40"	26°12'29.40"	7
124	Gelibolu	Yahya Çavuş Şehitliği ilerisi	40° 3'5.70"	26°10'34.30"	19
125	gelibolu	Seddülbahir ileri mevzileri	40° 3'15.10"	26°10'6.80"	38
126	Pınarhisar	Kırklareli yolu Dupnisa kavşağı yakını	41°41'38.60"	27°21'22.00"	242
127	kırklareli	Organize sanayi bölgesi karşısı	41°41'38.80"	27°19'20.20"	200
128	Kırklareli	Kofçaz yolu	41°51'48.10"	27°10'21.00"	399
129	kırklareli	Kofçaz yolu	41°54'48.00"	27°10'24.20"	470
130	Erikli	Kırklareli yolu 4. km	41°50'56.80"	27° 9'7.80"	327
131	Ahmetbey	Pınarhisar yolu ceviz köy	41°34'17.80"	27°34'35.70"	246
132	Poyralı köyü		41°36'44.40"	27°34'56.10"	242
133	Yenice köyü	Pınarhisar Demirköy yolu	41°43'49.80"	27°37'59.70"	434
134	Kaynarca	Pınarhisar-Kırklareli yolu	41°39'17.40"	27°29'19.30"	210
135	Kırklareli	Edirne yolu	41°40'30.30"	27° 1'25.20"	150
136	iskender kö	Edirne iskender köy	41°37'27.10"	26°40'35.70"	81
137	Ahmetbey	Cevizköy	41°25'29.90"	27°34'51.40"	132
138	Ahmetbey	Cevizköy	41°40'13.50"	27°36'45.80"	324
139	Pınarhisar	islambeyliköy	41°41'31.70"	27°37'12.10"	347
140	Demirköy		41°50'41.30"	27°48'23.20"	334

141	ğneada		41°51'39.40''	27°51'54.30''	294
142	Demirköy	Sivriler yolu	41°48'46.70''	27°47'55.50''	209
143	Demirköy	Sivriler yolu	41°47'44.60''	27°49'12.50''	257
144	Gelibolu	Ilgardere sapak civarı	40°16'26.76''	26°29'17.82''	41 m
145	Gelibolu	Ilgardere köyü, sapaktan 1 km ilerde	40°16'33.54''	26°29'3.72''	9 m
146	Eceabat	Kilitbahir-Abide arası, çeşmenin üst tar	40°08'10.20''	26°21'52.02''	42 m
147	Eceabat	Abide civarı	40°03'10.20''	26°13'20.28''	56 m
148	Eceabat	Anafartalar, Tuzgölü civarı	40°18'7.80''	26°16'32.76''	4 m
149	Gelibolu	Yalova köyü civarı	40°16'0.66''	26°24'23.28''	127 m
150	Enez	T.Ü. Dinlenme Tesisleri civarı, kumul	40°40'58.82"	26°3'57.16"	45m
151	Enez	Hisarlı Köyü Kuzey batısındaki tepeler	40°42'59.88''	26°11'58.68''	329 m
152	Enez	Enez-Sultaniçe sahili arası tuz gölü üst	40°38'13.14''	26°04'53.10''	9 m
153	Enez	Sultaniçe liman civarı	40°35'45.42''	26°07'30.36''	29 m
154	Uzunköprü	Çakmaklı-Saçlımüsellim arası	41°23'23.04''	26°39'42.06''	14 m
155	Uzunköprü	Uzunköprü İstasyon Değirmenci-Hamit	41°17'54.00''	26°41'738''	54 m
156	Uzunköprü	Yeniçiftlik köy merası	41°15'836''	26°36'44.28''	47 m
157	Uzunköprü	Uzunköprü- Keşan çıkışı havsa yol ayr	41°14'4.56''	26°41'16.86''	34 m
158	Uzunköprü	Kırcasalih- Keşan yolu 2. km	41°22'46.56''	26°47'8.04''	126 m
159	İpsala	Meriç- Küplü eskiyol vericilerin arka tarafı	41°10'36.66''	26°24'37.92''	11 m
160	İpsala	Karapınar-İbriktepe sapağı kanal boyu	41°06'18.54''	26°38'41.88''	38 m
161	Uzunköprü	Kurttepe- Kırcasalih arası 5. km	41°33'16.62''	26°37'31.56''	19 m
162	Uzunköprü	Kırcasalih- Çukurköy arası	41°31'4.50''	26°39'30.48''	94 m
163	Uzunköprü	Ömerbey- Çöpköy yolu 2. km	41°30'26.58''	27°23'42.78''	35 m
164	Uzunköprü	Çöpköy- Süleymaniye arası 3. km	41°29'59.16''	27°30'28.62''	157 m
165	Uzunköprü	Çöpköy- Süleymaniye arası 6. km	41°43'21.54''	27°06'49.80''	96 m
166	Uzunköprü	Çöpköy- Süleymaniye arası 10. km	41°46'3.60''	27°06'51.06''	257 m
167	Uzunköprü	Süleymaniye-Hasanpınar arası 4. km	41°54'39.54''	27°00'8.34''	365 m
168	Uzunköprü	Bıldır- Turnacı arası, Bıldır köyü çıkışı	41°41'47.04''	26°33'49.32''	38 m
169	Uzunköprü	Malkoçlar- Çöpköy arası 2.5 km	41°15'31.62''	26°47'22.32''	102 m
170	Uzunköprü	Ömerbey- Sultanşah arası	41°15'39.24''	26°52'9.48''	110 m
171	Uzunköprü	Gazimehmet- Elmalı arası	41°11'39.78''	26°54'11.28''	192 m
172	Uzunköprü	Yağmurca- Uzunköprü arası	41°11'42.72''	26°50'50.22''	79 m
173	Uzunköprü	Keşan -Uzunköprü arası Uzunköprü gir	41°14'4.56''	26°41'16.86''	34 m
174	Havsa	Söğütlüdere- Hasköy yolu, köy çıkışı	41°47'29.22''	27°16'46.26''	300 m
175	Havsa	Hasköy- Ürünlü arası Ürünlüye 1 km	41°56'2.16''	27°20'21.48''	489 m
176	Havsa	Naipyusuf mezarlığı çevresi	41°20'19.80''	26°53'48.66''	22 m
177	Havsa	Naipyusuf- Necatiye arası Necatiye'ye	41°12'23.82''	26°43'43.32''	83 m
178	Havsa	Oğulpaşa merası	41°49'46.68''	27°57'24.06''	-16 m
179	Havsa	Kuleli- Necatiye arası, Yolageldi yol	41°49'14.70''	27°57'5.22''	11 m
180	Havsa	Havsa- Osmanlı arası 2. km	41°58'32.34''	26°59'19.62''	424 m

181	Havsa	Hasköy- Kocahıdır arası	42°03'7.44''	27°07'37.86''	456 m
182	Edirne	Saçlımüsellim- Ekmekçi arası	41°25'36.60''	26°37'55.20''	45 m
183	Edirne	Ahiköy Uzgaç arası 2. km	41°46'58.08"	26°24'31.81"	103m
184	Edirne	Bayramdere- Üsküpdere arası	41°39'53.88''	27°21'7.20''	196 m
185	Merkez	İnece- Kırklareli arası	41°57'19.92''	27°17'49.38''	564 m
186	Merkez	Dereköy çıkışı- Doğa eğitim kampı çe.yo.	41°59'16.14''	27°15'42.18''	547 m
187	Lalapaşa	Demirköy- Hamzabeyli arası	41°56'37.68''	26°40'6.60''	416 m
188	Lalapaşa	Küçünlü köy merası	41°56'45.30''	26°45'1.92''	428 m
189	Lalapaşa	Hacılar- Vaysal 2.5 km	41°57'35.22''	26°47'56.76''	381 m
190	Lalapaşa	Karaorman mevkii	41°52'33.84''	26°46'14.46''	304 m
191	Kofçaz	Elmacık Kırklareli arası	41°30'2.70''	27°42'9.42''	185 m
192	Kofçaz	Kofçaz- Kocayazı arası 7. km	41°39'47.46''	27°54'2.52''	278 m
193	Kofçaz	Kofçaz- Kocayazı arası 7. km	41°39'21.66''	27°57'55.86''	131 m
194	Babaeski	Haznedar- Demirkapı arası 1. km	40°44'22.08''	26°41'7.02''	-9 m
195	Babaeski	Demirkapı-Terzili arası, Demirkapı köy	40°38'11.82''	26°36'6.36''	-21 m
196	Babaeski	Karacaoğlan- Yenimahalle arası 1. km	41°28'53.94''	27°12'54.48''	115 m
197	Babaeski	Yenimahalle- Nacak arası 1. km	41°32'20.22''	27°15'40.20''	155 m
198	Babaeski	E5- Mutlu sapağından 1 km sonra	40°46'38.28''	26°34'12.54''	66 m
199	Babaeski	Mutlu- Demirkapı arası 3. km	40°43'34.62''	26°29'17.16''	124 m
200	Babaeski	Kuzuçardağı- Taşağıl arası 2. km	41°32'59.22''	26°40'0.42''	87 m
201	Babaeski	Taşağıl- Yeniköy arası 4. km	41°31'31.92''	27°12'1.08''	123 m
202	Babaeski	Yeniköy- Çavuşköy arası	41°15'9.00''	26°31'30.30''	57 m
203	Babaeski	Karabayırköyü içi okul bahçesi	41°12'27.18''	26°26'39.30''	57 m
204	Babaeski	Erikleryurdu- Kumrular arası 2. km	41°18'48.24''	27°19'39.90''	97 m
205	Babaeski	Erikleryurdu- Kumrular arası 3. km	41°16'53.22''	27°17'53.94''	85 m
206	Lüleburgaz	Hamiatabat- Kırıkköy arası 1. km	41°15'23.28''	27°26'36.78''	123 m
207	Pınarhisar	Kırklareli- Pınarhisar arası 4. km	41°42'27.72''	27°15'51.66''	160 m
208	Pınarhisar	Kaynarca- Sofuhalil arası 4. km	41°41'19.80''	27°27'14.82''	231 m
209	Pınarhisar	Kaynarca- Hacıfaklı arası 6. km	41°42'30.60''	27°27'20.34''	271 m
210	Pınarhisar	Hacıfaklı- Çayırdere arası 4. km	41°42'19.14''	27°29'29.10''	241 m
211	Pınarhisar	Çayırdere- Kurudere arası 3. km	41°43'19.56''	27°32'7.20''	340 m

Deneme alanının iklim ve toprak özellikleri

Tarla denemeleri Tekirdağ Namık Kemal Üniversitesi Ziraat Fakültesi Tarla Bitkileri Bölümü Araştırma ve Uygulama arazisinde yürütülmüştür. Deneme alanı Trakya bölgesinin Marmara Denizi kıyısında, killi-tınlı topraklar üzerinde, 550 mm mevsimsel yağış altında yer almaktadır. Araştırmanın yürütüldüğü yer ve yıllara ilişkin iklim özellikleri Çizelge 3'te verilmiştir.

Çizelge 3. Deneme alanına ait Tekirdağ ili iklim verileri.

Aylar	Ortalama sıcaklık (°C)			Toplam yağış (mm)			Oransal nem (%)		
	2014-2015	2015-2016	Uzun yıllar*	2014-2015	2015-2016	Uzun yıllar*	2014-2015	2015-2016	Uzun yıllar *
Kasım	11.2	13.8	11.7	35.2	48.5	62.5	85.2	80.7	84.0
Aralık	9.3	7.3	7.2	80.3	0.7	82.5	89.3	79.9	83.6
Ocak	5.8	5.6	5.2	61.5	70.7	62.1	81.9	80.0	84.0
Şubat	6.5	9.7	5.7	90.2	68.4	64.6	84.8	85.5	81.4
Mart	8.5	10.4	8.0	30.6	32.6	57.4	81.9	80.3	80.7
Nisan	11.4	15.6	12.2	22.9	22.9	41.5	74.3	72.2	78.2
Mayıs	17.7	17.9	17.6	28.1	28.6	33.8	75.2	74.4	75.1
Haziran	21.3	23.6	22.2	58.4	35.0	35.0	73.3	72.2	72.6
Toplam		-	-	552.6	304.9	529.7		-	-
Ortalama	11.9	13.37	11.7	-	-	-	80.74	78.15	79.95

(*Anonim, 1960-2016)

Deneme alanının toprakları killi-tınlı bir bünyeye sahiptir. Deneme alanında 0-20 cm ve 20-40 cm toprak seviyelerinin toprak testi değerleri 6.25-6.52 pH, %0.01 kireç, 1.5-1.6 ppm P_2O_5, 429-326 ppm Mg, 25-27 ppm Fe olarak belirlenmiştir.

Çizelge 4. Araştırmanın ilk yılında toplanan genotiplerden seçilen ve ekilen fiğ türlerinin bulundukları yükselti ve koordinatları (2014)

Tür	Genotip No:	Yükselti (m)	Enlem (Kuzey)	Boylam (Doğu)
Adi fiğ *(V. sativa)*	6-20	9	40°59'34.92"	25°57'14.10"
	33-1	11	40°41'35.76"	27°17'29.70"
	37-1	84	41°10'59.60"	27°27'49.38"
	22-5	194	41°19'36.54"	28°15'57.92"
	3-3	126	40°51'11.82"	27°27'12.96"
	10-31	61	41°9'23.64"	28°27'16.38"
	15-47	136	41°21'11.52"	28°27'13.80"
	(15-1)-5	136	41°21'11.52"	28°27'13.80"
	21-2	158	41°17'51.42"	28°14'15.72"
	15-5	136	41°21'11.52"	28°27'13.80"
	15-38	136	41°21'11.52"	28°27'13.80"
Macar fiği *(V. pannonica)*	17-10	83	41°0'7.74"	27°33'22.50"
	15-32	136	41°21'11.52"	28°27'13.80"
	7-31	25	41°2'7.08"	27°57'12.84"
	15-40	136	41°21'11.52"	28°27'13.80"
Tüylü Fiğ *(V. villosa)*	14O06	67	41°38'50.33"	26°37'03.88"
	14O05	67	41°38'50.33"	26°37'03.88"
Sarıçiçekli fiğ *(V. lutea)*	7-33	25	41°2'07.08"	27°57'12.84"
	7-6	25	41°2'7.08"	27°57'12.84"
	22-3	194	41°19'36.54"	28°15'7.92"
	8-10	103	41°06'41.10"	27°55'30.00"
	14U01	116	41°41'38.80"	27°19'20.20"
	14-8	136	41°18'8.46"	28°27'41.46"
	8-4	103	41°6'41.10"	27°55'30.00"
	10-30	61	41°9'23.64"	28°27'16.38"
	14O03 (201)	67	41°38'50.33"	26°37'03.88"
Kuş fiği *(V. cracca)*	3-21	126	40°51'11.82"	27°27'12.96"
	7-7	45	41°2'07.08"	27°57'12.84"
	7-11	25	41°2'09.08"	27°57'11.82"
	17-11	83	41°0'07.74"	27°33'22.50"

Materyal seçimi

Trakya bölgesi doğal florasında belirlenen 23 farklı tür arasından en iyi gelişme gösteren ve buna göre seçilen altı farklı fiğ türü Adi fiğ (*Vicia sativa* L.), Macar fiği (*Vicia pannonica* Crantz.), tüylü fiğ (*Vicia villosa* Roth.), kuş fiği (*Vicia cracca*, L.), sarıçiçekli fiğ (*Vicia lutea* L.) ve Melez fiğ (*Vicia hybrida*)) araştırmanın ilk yılında (2014-2015) ve ikinci yılında (2015-2016) Tekirdağ Namık Kemal Üniversitesi Ziraat Fakültesi Tarla Bitkileri deneme ve uygulama alanına ekilmiştir. Tarla denemelerinin her iki yılında da iyi gelişme özelliğine sahip yüksek boylu ve yüksek tohum verimine sahip türler seçilmiştir. Bu nedenle, materyal olarak kullanılan tür ve genotipler her iki yılda da farklı olmuştur. İlk yıl *V. sativa*, *V. pannonica*, *V. villosa*, *V. lutea* ve *V.cracca* türlerine ait genotipler (Çizelge 4), İkinci yıl ise *V. sativa*, *V. pannonica*, *V. villosa*, *V. lutea* ve *V. hybrida* türlerine ait genotipleri kullanılmıştır (Çizelge 4).

Çizelge 5. Araştırmanın ikinci yılında toplanan genotiplerden seçilen ve ekilen fiğ türlerinin bulundukları yükselti ve koordinatları (2015)

Tür	Genotip No:	Yükselti (m)	Enlem (Kuzey)	Boylam (Doğu)
Adi fiğ *(V. sativa)*	15-13	136	41°21'11.52"	28°27'13.80"
	15-5	136	41°21'11.52"	28°27'13.80"
	15-F-20 (136)	56	40°03'10.20"	26°13'20.28"
	15-I-01 (134)	38	40°16'5.59"	26°29'0.62"
	15-I-08 (136)	56	40°03'10.20"	26°13'20.28"
	15-K (67)	346	41°58'15.56"	26°56'32.04"
	15-K-17 (116)	200	41°41'38.80"	27°19'20.20"
Macar fiği *(V. pannonica)*	36-1	107	41°28'34.78"	27°20'35.91"
	15-14	61	41°9'23.64"	28°27'16.38"
	15-I-15 (201)	67	41°38'50.33"	26°37'03.88"
	121-7	370	41°36'44.60"	27°34'56.10"
Tüylü fiğ *(V. villosa)*	14-O-02	67	41°38'50.33"	26°37'03.88"
	14-O-03	67	41°38'50.33"	26°37'03.88"
	14-O-05	67	41°38'50.33"	26°37'03.88"
	14-O-06	67	41°38'50.33"	26°37'03.88"
	14-P-197 (76)	177	41°30'2.70"	27°42'3.42"
	14-P-105 (76)	177	41°30'2.70"	27°42'3.42"
	15-7	136	41°21'11.52"	28°27'13.80"
	15-I-16 (95)	94	41°23'33.00"	26°39'31.40"
	15-I-23A (144)	54	41°17'54.00"	26°41'07.38"
	15-I-43 (146)	110	41°14'4.56"	26°41'16.86"
Sarıçiçekli fiğ *(V. lutea)*	6-5	9	40°59'34.92"	27°57'14.10"
	96-1	37	41°27'34.90"	26°37'29.50"
	7-6	25	41°2'7.08"	27°57'12.84"
	10-3	63	41°9'23.64"	28°27'16.38"
	15-I-24 (144)	54	41°17'54.00"	26°41'07.38"
	14-U-01 (116)	200	41°41'38.80"	27°19'20.20"
Melez fiğ *(V. hybrida)*	10-4	244	40°50'43.09"	27°26'8.01"
	22-1	30	41° 4'33.09"	28° 9'20.05"
	6-4	169	40°54'42.02"	27°17'26.01"

Araştırmanın ilk yılında tohum ekimi 11 Kasım 2014 tarihinde 0,5 m sıra aralığındaki 2,0 m uzunluğundaki tek bir sıraya 0,25 m sıra üzeri mesafe ile her bir genotip için 9 tohum ekilmiştir. İkinci yılda farklı lokasyonlardan toplanan farklı türlere ait farklı genotipler genotip bazında daha fazla tohum olması nedeni ile her genotipe ait 21 tohum 3 Kasım 2015 tarihinde 0,5 m sıra arası ve 0,25 m sıra üzeri mesafe ile 5 m uzunluğundaki sıralara her bir genotip için bir sıra olacak şekilde elle ekilmiştir. Deneme alanı ekimden önce her iki yılda da 80 kg/ha P_2O_5 kullanılarak gübrelenmiştir. Tarla çalışması boyunca temiz bir tarla için gerektiğinde elle yabancı ot mücadelesi

yapılmıştır. Fiğ tür ve genotiplerinin çiçeklenme gün sayısı; ekim tarihi ile sıradaki bitkilerin %50'sinin 1-4 çiçek açtığı tarih arasındaki gün sayısı olarak belirlenmiştir. Meyve oluşturma gün sayısı; ekim tarihi ile sıradaki bitkilerin %50'sinde toprak yüzeyine yakın bölgede 1-4 meyve oluşturdukları tarih arasındaki gün sayısı olarak kaydedilmiştir. Meyve olgunlaştırma gün sayısı ekim tarihi ile sırada bitkilerin %50 sinde 1-4 meyvenin tamamen kahverengi renk aldığı tarih arasındaki gün sayısı olarak saptanmıştır. Hasat gün sayısı ise; ekim tarihinden itibaren herbir genotip için sıradaki bitkilerin %50 sinde meyvelerin alttan itibaren tamamen kuruduğu, meyve çatlatmasına müsaade edilmeden toplandığı tarih arasındaki fark gün olarak belirlenmiştir.

Bitki boyu, tesadüfen belirlenen 3 bitkide çiçeklenme sonunda toprak yüzeyi ile bitkinin uç noktası arasındaki uzunluk ortalamaları bitki boyu olarak, aynı bitkilerde yapılan ölçümlerde; Toprak yüzeyinden itibaren 2. ve 3. boğum arası vernier bölmeli kumpasla ölçülmüş ve ortalaması sap çapı olarak, meyve içeren dallar ana gövde hariç sayılarak ortalaması alınmış ve yan dal sayısı olarak kaydedilmiştir. Tane hasadından önce diğer tüm ölçümlerin yapıldığı aynı bitkilerde meyveler sayılmış ve ortalaması bitkide meyve sayısı olarak belirlenmiştir. Yabani karakterde olan türlerin tohum hasadı elle yapılarak (210-217 gün) kese kağıdı içinde (3 gün) muhafaza edilmiş sonrasında tohum verimi belirlenmiştir. Önemli karakterler arasında yeralan 1000 tane ağırlığı, hersıraya ait bitkilerin tohum hadadından sonra 4x100 adet tohum sayılarak 0,01 g hassasiyetli tartı ile tartılarak ortalaması alınmış ve 10 çarpılarak bulunmuştur (Orak ve Elçi, 1990) .

Verilerin değerlendirilmesi

Veriler Windows için SPSS (Anonim, 2018) kullanılarak analiz edilmiştir. Her iki yılda da beş farklı türe ait 30 farklı fiğ genotipinin fenolojik ve morfolojik karakterleri ile verim ve verim unsurlarına ilişkin ortalama değerler, standart hata ve varyasyon katsayısı belirlenmiştir. Ayrıca, bunlar çok değişkenli analizlere dahil edilen tüm değişkenlerin, genotip ve türleri gruplandırmak için çok değişkenli analiz yöntemi kullanılarak farklılıklar belirlenmiştir.

BULGULAR ve TARTIŞMA

Sörvey çalışmaları ile toplanan 23 farklı fiğ türüne ait 246 farklı genotip Çizelge 1'de tür isimleri ile birlikte bulundukları lokalite ve yükseltileri listelenmiştir.

Tek yıllık türler içerisinde yaygın olarak bulunan *V. lathyroides'*ten 23 adet, *V. hybrida'*dan 21 adet ve *V. sativa* ssp. *nigra* var. nigra'dan ise 20 adet farklı genotip belirlenmiştir. Toplam olarak 33 farklı fiğ genotipi içinde yeralan ancak yaygın olmadığı belirlenen türler arasında *V. cracca* ssp. cracca, *V. crocea*, *V. cuspidata*, *V. grandiflora* var. disecta, *V. melanops*, *V. meyeri*, *V. sibthorpii* ve *V. villosa* ssp. villosa bulunmaktadır. Ayrıca, bölgede belirlenen çok yıllık türler arasında *V. cassubica*, *V. cracca* ssp. Gerardi ve *V. cracca* ssp. stenophylla ve *V. crocea* bulunmaktadır. *Vicia villosa*'nın *alt türleri* olarak *V. villosa* ssp. *dasycarpa*, *V. villosa* ssp *eriocarpa* ve *V. villosa* ssp. *villosa'nın* tek ve iki yıllık özelliğe sahip genotipleri saptanmıştır. Bölge doğal florasında bulunan fiğ türlerinin önemli bir bölümünün tek yıllık olduğu, iki yıllık özelliğe sahip olan *Vicia villosa* ssp. *dasycarpa*, *Vicia villosa* ssp. *eriocarpa* ve *Vicia villosa* ssp. *villosa'nın* bölgede mevcut olduğu belirlenmiştir.

. *gerardii, V. hirsuta ve V. lathyroides* türlerine rastlanmakta iken alçaklarda (100-300 m) *V. bithynica , V. cassubica, V. cracca* subsp. *stenophylla, V. galileae, V. grandiflora, V. grandiflora* var. *grandiflora, V. hirsuta, V. hybrida, V. lutea, V. lutea* var. *hirta, V. narbonensis, V. pannonica* subsp. *pannonica* , *V. pannonica* subsp. *purpurascens, V. parviflora, V. peregrina, V. sativa* subsp. *sativa, V. sativa* subsp. *nigra* var. *nigra, V. sativa* subsp. *nigra* var. *segatialis ve V. villosa* subsp. *dasycarpa* türleri belirlenmiştir. *V. lathyroides ve V. grandiflora* var. *grandiflora* türleri sörvey çalışmalarının yapıldığı tüm yüksekliklerde sıklıkla ratlanan türler olmuştur (Çizelge 6).

Çizelge 6'da Trakya bölgesi doğal florasından toplanan farklı fiğ tür ve alt türlerine ait genotiplerin toplandığı lokalitelerin yükseltileri verilmiştir. Toplanan türler arasında en yüksek frekans *V. lathyriodies*, *V. hybrida* ve *V. sativa* ssp. nigra var. nigra türlerinde bulunmuştur. Daha belirgin genetik ve agronomik gereksinime sahip *V. meyeri* ve *V. cuspitada* türleri 200-300 m. yükseklikten toplanmıştır (Çizelge 6).

Sörvey çalışmaları sonucunda toplanan fiğ türleri her iki yılda da toplandığı yılın kasım ayında tarlaya ekilmiştir. Fiğ türlerine ait tarla denemesi sonuçları birinci yıl (2014-2015 yetiştirme periyodu) ve ikinci yıl (2015-2016 yetiştirme periyodu) verileri olarak sırası ile Çizelge 7 ve 8'de verilmiştir. Her bir türe ait ortalamalar, ortalamaların standart hataları ve varyasyon katsayıları da ortalama değerlere göre gösterilmiştir.

Araştırmanın birinci yılında (2014-2015) *Vicia sativa*, *Vicia pannonica*, *Vicia villosa*, *Vicia lutea* ve *Vicia cracca* türlerinin fenolojik, morfolojik özellikleri ile verim ve verim unsurları saptanmıştır. Türlerin ortalama değerleri ile standart hata ve varyasyon katsayıları Çizelge 8'de gösterilmiştir.

Araştırmanın ilk yılında (2014-2015) en erken çiçeklenen tür *Vicia lutea* (sarı çiçekli fiğ; 169.56 gün) , olup bunu sırası ile *Vicia pannonica* (Macar fiği; 171.75 gün) *Vicia sativa* (adi fiğ; 173.90 gün) *Vicia villosa* (tüylü fiğ) takip etmiştir. En geç çiçeklenen ise *Vicia cracca* (kuş fiği; 176.67 gün) olmuştur. Çiçeklenme döneminden sonra meyve oluşumuna kadar geçen sürede en erken meyve oluşumu 182.10 gün ile *Vicia sativa*'da en geç ise 187.67 gün ile *Vicia cracca'*da belirlenmiştir. En kısa sürede meyve olgunlaştıran *Vicia sativa* (195.40 gün) olurken, en uzun sürede meyve olgunlaştıran (212.75 gün) ve tane dökmeyen *Vicia pannonica* olmuştur (Çizelge 7). Çiçeklenmede 3. sırada yeralan *Vicia sativa* genotipleri, *Vicia lutea* ve *Vicia pannonica* gibi kışlık özelliğe sahip olmadığı için, çiçeklenme döneminden sonra havaların ısınması ile hızlı gelişerek en erken meyve olgunlaştıran tür olmuştur.

Çizelge 6. Sörvey çalışmaları sonucunda farklı yüksekliklerden toplanan fiğ türlerine ilişkin genotip sayıları

	Tür	Yükseklik						Toplam
		1-100 m	101-200 m	201-300 m	301-400 m	401-500 m	501-600 m	
1	1. *V. articulata*			1 (50)	1 (50)			2
2	2. *V. bithynica*	2 (100)						2
3	3. *V. cassubica*	2 (40)			3 (60)			5
4	4. *V. cracca* subsp. *cracca*					1(100)		1
5	4. *V. cracca* subsp. *gerardii*				1 (33)		2 (67)	3
6	4. *V. cracca* subsp. *stenophylla*	1 (12.5)	3 (37.5)		2 (25)	2 (25)		8
7	5. *V. crocea*				1 (100)			1
8	6. *V. cuspidata*			1 (100)				1
9	7. *V. galileae*	1 (14.3)	6 (85.70)					7
10	8. *V. grandiflora*	2 (14.3)	3 (21.4)	2 (14.3)	2 (14.3)			9
11	8. *V. grandiflora* var. *dissecta*				1 (100)			1
12	8. *V. grandiflora* var. *grandiflora*	2 (12.5)	4 (25)	3 (18.75)	2 (12.5)	4 (25)	1 (6.25)	16
13	9. *V. hirsuta*	4 (40)	4 (40)		1(10)		1(10)	10
14	10. *V. hybrida*	13 (61.9)	6 (28.5)	2 (9.5)				21
15	11. *V. lathyroides*	10 (43.4)	6 (4.3)	2 (8.6)	3 (13.04)	1 (4.3)	1 (4.3)	23
16	12. *V. lutea*	1 (25)	3 (75)					4
17	12. *V. lutea* var. *hirta*	10 (66.7)	5 (33.3)					15
18	13. *V. melanops*		1 (100)					1
19	14. *V. meyeri*			1 (100)				1
20	15.*V. narbonensis*	6 (66.7)	3 (33.3)					9
21	16. *V. pannonica* subsp. *pannonica*	5 (45.45)	5 (45.45)		1 (9.09)			11
22	16. *V. pannonica* subsp. *purpurascens*	8 (57.14)	4 (28.57)	1 (7.14)	1 (7.14)			14
23	17. *V. parviflora*	3 (75)		1 (25)				4
24	18. *V. peregrina*	7 (53.84)	5 (38.46)		1 (7.69)			13
25	19. *V. sativa* subsp. *sativa*	8 (50)	8 (50)					16
26	19. *V. sativa* subsp. *incisa* var. *incisa*		1 (25)	1 (25)	1 (25)	1 (25)		4
27	19. *V. sativa* subsp. *incisa* (Bieb.) Arc. var. *cordata* (Wulfen ex Hoppe) Arc.			1 (50)		1 (50)		2
28	19. *V. sativa* subsp. *nigra* var. *nigra*	10 (50)	7 (35)		1 (5)	2 (10)		20
29	19. *V. sativa* subsp. *nigra* var. *segatialis*	6 (40)	5 (33.3)	1 (6.7)	2 (13.3)	1 (6.7)		15
30	20. *V. sibthorpii*				1 (100)			1
31	21. *V. tetrasperma*				1 (50)	1 (50)		2
32	22. *V. villosa* subsp. *dasycarpa*	1 (33.3)	1 (33.3)		1 (33.3)			3
33	22. *V. villosa* subsp. *villosa*				1 (100)			1
Toplam		*102*	*80*	*17*	*28*	*14*	*5*	*246*

Araştırma materyali olan *Vicia* türlerinin Kicheva ve Angelova (2006) tarafından 148 gün olarak bildirilen meyve olgunlaştırma gün sayısından daha uzun bir büyüme sezonu olduğu görülmüştür. Bulgularımız ile kaynak bildirişleri arasındaki farkın bölgesel ve genotip farklılığından kaynaklandığı söylenebilir. Araştırmanın ilk yılında en erken tohum hasadı 220.40 gün ile *Vicia sativa*'da, en geç ise 225.67 gün ile *Vicia cracca'*da saptanmıştır. Bitki boyu ölçümleri yönünden türler arasında önemli farklar saptanmıştır. En yüksek bitki boyu *Vicia villosa'*da

(92,25 cm), en kısa bitki boyu ise (55.33 cm) *Vicia cracca'*da belirlenmiştir. Elde ettiğimiz sonuçlar, Mihailovich ve ark. (2008) bulgularından (158 cm) düşük bulunmuştur. Farklılığın sebebi olarak bölgenin ekolojik koşulları gösterilebilir.

Araştırmamızda yükseklikle birlikte tür sayısının azaldığı belirlenmiştir. 501-600 m yükseklikte *V. cracca* subsp

Morfolojik özelliklerden biri olan sap çapı en düşük 2,32 mm ile *Vicia lutea'*da, en yüksek ise 3,75 mm ile *Vicia pannonica*'da belirlenmiştir. En fazla dal sayısı 15.56 adet ile *Vicia lutea'*da, en düşük ise 10.00 adet ile *Vicia villosa*'da saptanmıştır. Bitkide meyve sayısının en yüksek olduğu tür 54.00 adet ile *Vicia pannonica,* en düşük ise 36.67 adet ile *Vicia cracca*'da tespit edilmiştir. En iri tohumlar 51.88 g bin tane ağırlığına sahip *Vicia sativa*'da en küçük tohumlar ise 33.79 g bin tane ağırlığı ile *Vicia cracca*'da saptanmıştır (Çizelge 7).

En yüksek bitki tohum verimi 28,48 g ile *Vicia villosa'*da, en düşük ise 3,96 g ile *Vicia cracca'*da belirlenmiştir (Çizelge 7).

Araştırmanın ikinci yılında (2015-2016) *Vicia sativa*, *Vicia pannonica*, *Vicia villosa*, *Vicia lutea* ve *Vicia hybrida* türlerinin fenolojik, morfolojik özellikleri ile verim ve verim unsurları saptanmıştır. Türlerin ortalama değerleri ile standart hata ve varyasyon katsayıları Çizelge 8'de gösterilmiştir. İkinci yıla ait verilerimize göre: En geç çiçeklenme 180.33 gün ile *Vicia hybrida'da,* en erken çiçeklenme ise 170.05 gün ile *Vicia lutea'*da olmuştur. En erken meyve bağlama başlangıcı 189.33 gün ile *Vicia hybrida*'da belirlenirken en geç meyve bağlama başlangıcı 196.15 gün ile *Vicia villosa*'da saptanmıştır. En uzun meyve olgunlaştırma gün sayısı *Vicia villosa*'da 214.77 gün olarak kaydedilirken, en erken meyve olgunlaştırma, 201.00 gün ile *Vicia sativa'*da belirlenmiştir.

Fiğ türleri ekimden itibaren 212.67 ve 226.46 gün arasında tohum hasadına gelmiştir. En uzun bitki boyu 89.41 cm ile *Vicia villosa*'da, en kısa bitki boyu ise *Vicia pannonica*, *Vicia lutea* ve *Vicia sativa*'da sırasıyla 35.30, 36.13 ve 36.21 cm olarak saptanmıştır. Fiğ türleri arasında sap çapı ve yan dal sayısı bakımından belirgin farklılıklar bulunmamıştır. En yüksek sap çapı *Vicia sativa'da* (2.80 mm) ve en düşük ise *Vicia villosa'*da (2.11 mm) saptanmıştır (Çizelge 8). En fazla yan dal sayısı *Vicia hybrida* ile *Vicia pannonica'*da 19.44 ve 16.84 adet olarak belirlenmiştir.

En yüksek bitki tohum verimi 6.30 g ile *Vicia villosa*'da kaydedilmiş, ancak aynı tür bu karakter için en yüksek CV'ye sahip olmuştur. Bitki tohum verimi en düşük 0.42 g ile *Vicia pannonica*'dan elde edilmiştir. Bin tane ağırlığı 53.76 g ile en yüksek *Vicia sativa'*da belirlenirken, en düşük 1000 tane ağırlığı *Vicia lutea*'da 34.70 g olarak saptanmıştır.

Çizelge 7. Yabani fiğ türlerinin fenolojik ve morfolojik özelliklerine ait ortalama veriler, standart hata ve değişim katsayısına ilişkin değerler (2014-2015).

Karakterler	*Vicia sativa*			*Vicia pannonica*			*Vicia villosa*			*Vicia lutea*			*Vicia cracca*		
	Ort.	Se	Cv	Ort.	Se	Cv	Ort.	Se	Cv	Ort.	Se	Cv	Ort.	Se	Cv
Çiçeklenme gün sayısı	173.90	1.11	2.02	171.75	2.59	3.02	174.25	1.65	1.90	169.56	1.66	2.92	176.67	3.53	3.46
Meyve oluşturma gün sayısı	182.10	1.05	1.32	183.50	2.63	2.87	182.50	1.71	1.87	183.11	1.67	2.74	187.67	2.60	2.40
Meyve olgunlaştırma gün sayısı	195.40	0.98	1.59	212.75	2.93	2.75	209.00	0.70	0.68	205.33	1.25	1.82	208.33	0.33	0.28
Hasat gün sayısı	220.40	0.96	1.37	223.25	1.89	14.25	224.25	0.95	0.84	222.89	1.07	1.44	225.67	0.67	0.51
Bitki boyu (cm)	62.50	4.74	23.96	69.00	5.73	16.61	92.25	9.40	20.38	76.22	8.30	32.69	55.33	3.84	12.03
Sap çapı (mm)	2.95	0.02	23.23	3.75	0.01	7.70	3.00	0.04	27.22	2.32	2.39	30.89	2.67	0.07	43.30
Yandal dal sayısı	12.60	2.03	50.91	10.75	1.32	24.47	10.00	1.68	33.67	15.56	1.38	26.53	12.67	2.91	39.74
Bitkide meyve sayısı	40.00	6.27	49.58	43.50	6.67	30.64	54.00	11.89	44.03	51.89	8.01	46.31	36.67	6.77	31.96
1000 tane ağırlığı (g)	51.88	1.92	11.73	39.47	2.32	11.75	37.22	7.38	39.65	34.63	2.40	20.78	33.79	4.24	21.75
Bitkide tohum ağırlığı (g)	17.68	8.81	157.57	19.42	5.62	57.89	28.48	7.63	53.55	6.64	16.78	75.75	3.96	1.04	45.34

Çizelge 8. Yabani fiğ türlerinin fenolojik ve morfolojik özelliklerine ait ortalama veriler, standart hata ve değişim katsayısına ilişkin değerler (2015-2016).

Karakterler	*Vicia sativa*			*Vicia pannonica*			*Vicia villosa*			*Vicia lutea*			*Vicia hybrida*		
	Ort.	Se	Cv	Ort.	Se	Cv	Ort.	Se	Cv	Ort.	Se	Cv	Ort.	Se	Cv
Çiçeklenme gün sayısı	170.38	2.15	3.58	169.50	0.50	0.42	173.38	1.50	3.12	170.05	0.96	3.67	180.33	5.78	5.56
Meyve oluşturma gün sayısı	191.63	1.50	2.21	197.50	0.50	0.36	196.15	0.95	1.75	192.75	3.45	3.58	189.33	0.67	0.61
Meyve olgunlaştırma gün sayısı	201.00	0.71	0.10	205.50	7.50	5.16	214.77	0.80	1.35	204,00	1.08	1.06	203.00	1.53	1.30
Hasat gün sayısı	213.13	1.11	1.47	219,00	3.00	1.94	226.46	1.67	2.67	219.75	2.72	2.48	212.67	4.71	4.71
Bitki boyu (cm)	36.21	4.76	37.17	35.30	8.30	33.25	89.41	8.70	35.07	36.13	6.96	27.46	40.95	5.75	24.30
Sap çapı (mm)	2.80	0.29	28.80	2.49	0.22	12.24	2.11	0.16	27.25	2.29	0.35	30.50	2.36	0.26	19.28
Yandal sayısı	10.92	1.36	35.30	16.84	3.17	26.59	12.13	1.03	30.79	10.71	2.31	43.23	19.44	3.07	27.35
Bitkide meyvea sayısı	41.65	5.13	34.84	21.38	0.55	3.64	31.19	3.24	37.48	31.36	1.69	10.80	38.02	9.20	41.91
1000 tane ağırlığı (g)	53.76	1.97	10.36	36.95	1.39	5.30	35.86	1.05	10.58	34.70	2.90	16.70	36.28	3.56	16.98
Bitki tohum verimi (g)	4,55	3,73	232,48	0,42	0,15	50,51	6,30	4,50	257,12	3,35	0,13	77,46	3,26	2,58	136,93

Biplot analizi

Tarla çalışmalarının ilk yıl verilerinin Biplot yöntemi (Yan ve Rajcan, 2002) kullanılarak elde edilen grafiğin değerlendirilmesi sonucunda ilk iki boyutta toplam varyasyonunun %64,6'sının açıklandığı görülmüştür. Orta seviye olarak kabul edilen bu oran, genotiplerin özellikleri arasındaki ilişkinin karmaşıklığını yansıtmaktadır. İlk iki temel bileşen (PC1 ve PC2) sırasıyla %34,4 ve %30,2'sini açıklamıştır. Biplot analizi sonucunda, özellikler ve çeşitler arasındaki ilişkilerin görselleştirilmesini kolaylaştırmak için biplot orijininden çeşitlerin her bir bölümüne ait vektörler uzatılmıştır (Şekil 3).

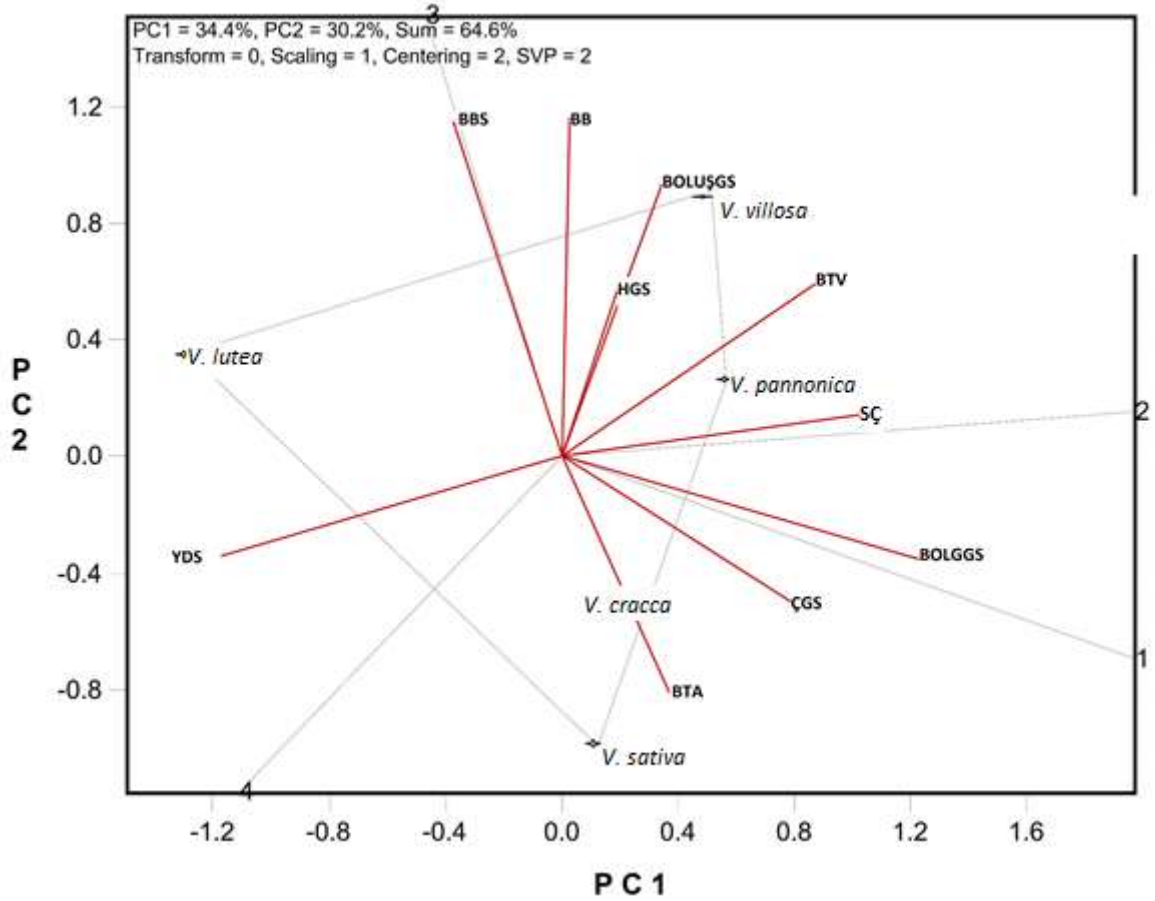
Biplot analizi araştırmanın ilk yılında 5 farklı fiğ türünde (*Vicia sativa*, *Vicia pannonica*, *Vicia villosa, Vicia cracca* ve *Vicia lutea*) gözlemlenen 10 farklı özelliğe ilişkin veriler dikkate alınarak hesaplanmıştır. Elde edilen değerler grafik olarak Şekil 3'te verilmiştir. Şekilden de görüleceği üzere Biplot'un başlangıç noktasına en yakın veya en uzak olan türler bazı özellikler bakımından en iyi veya uygun olmayan türler olabilirler. Aynı sektörde yer alan *Vicia pannonica* ve *Vicia villosa* köşegenleri oluşturan türler olarak meyve olgunlaştırma gün sayısı, hasat gün sayısı, bitki boyu, yandal sayısı, bitki tohum verimi ve sap çapı bakımından yapılacak seleksiyonlarda öne çıkan türler olmuştur.

Vicia sativa 1000 tane ağırlığının yüksek olması ile *Vicia pannonica ise* en geç çiçeklenen tür olma özelliği ile öne çıkmıştır.

Vicia lutea'nın köşegenlerde yer aldığı ve yüksek yandal sayısına sahip olduğu belirlenmiştir. (Şekil 3).

Şekil 3'te de görüleceği üzere Biplot poligon grafiğinin dört farklı köşegeninde yer alan türlere ait genotipleri kullanılarak ıslah sürecinin başlatılması mümkündür. Karakterler arasında ikili ilişkiler için yine Şekil 3'e göre hasat gün sayısı ile meyve olgunlaştırma gün sayısı arasında; bitkide meyve sayısı ile bitki boyu arasında; bitki tohum verimi ile sap çapı arasında meyve olgunlaştırma gün sayısı ile hasat gün sayısı arasında belirgin ve önemli ilişki olduğu saptanmıştır.

Ölçüm karakterlerimizden sap çapı ile yan dal sayısı arasında; bitkide meyve sayısı ile sap çapı arasında; meyve olgunlaştırma gün sayısı ve yan dal sayısı arasında; bitki tohum verimi ve yan dal sayısı arasında (r=Cos180=-1) gösterdiği gibi negatif bir ilişki bulunmaktadır (Şekil 3).



Şekil 3. Beş farklı yabani fiğ türünün ilk yıl elde edilen fenolojik ve morfolojik verilerine ait Bi-plot poligon grafiği (2015) Not: (BB: Bitki boyu; BBS: Bitkide meyve sayısı; BOLUŞGS: Meyve oluşturma gün sayısı; HGS: Hasat gün sayısı; BTV:

Bitki tohum verimi; SÇ: Sap çapı; BOLGGS: Meyve olgunlaştırma gün sayısı; ÇGS: Çiçeklenme gün sayısı; BTA: Bin tane ağırlığı; YDS: Yan dal sayısı)

Yan dal sayısı ve 1000 tane ağırlığı; bitki tohum verimi ve bitkide meyve sayısı ve sap çapı arasında yaklaşık 90 derecelik yakın açı ile gösterildiği gibi (r=Cos 90=0) herhangi bir ilişkinin olmadığı belirlenmiştir. Elde edilen analiz sonucunda toplam varyasyonun yaklaşık %65'lik kısmını açıkladığı için Biplot analizinde değişkenlerdeki varyasyonunu bir kısmının (%35) açıklanamadığı görülmüştür.

Parametreler arasındaki korelasyon katsayısını tahmin etmek için biplotun vektör görünümü, karakterler arasındaki ilişkileri anlamak için de fiğ türlerinin vektörleri arasındaki açı kullanılmıştır (Şekil 3). Ek olarak, *Vicia pannonica* ve *Vicia lutea* arasında herhangi bir yakınlık olmadığı; aynı görüntünün *Vicia sativa* ve *Vicia pannonica* arasında da (r= cos 90=0) herhangi bir ilişki olmadığı belirlenmiştir. *Vicia sativa* ile *Vicia villosa* arasında 180 dereceye yakın açının işaret ettiği gibi negatif bir korelasyon belirlenmiştir. Elde edilen bu sonuç ile *Vicia sativa, Vicia pannonica, Vicia villosa, Vicia cracca ve Vicia lutea'nın* morfolojik özelliklerinin birbirinden tamamen farklı olduğu ve belirgin varyasyon gösterdiği ve incelenen özellikler dikkate alınarak kıraç koşullarında yeni türlerin ıslahında genetik kaynak olarak kullanılmasının mümkün olduğu belirlenmiştir. Biplot analizinin değerlendirildiği bölümde Şekil 3'de görüldüğü üzere merkeze yakınlık durumuna göre, bitki tohum veriminin öne çıktığı belirlenmiştir.

Sonuç

Araştırma sonuçlarından *Vicia villosa* ve *Vicia pannonica'*nın bitki boyu, meyve olgunlaştırma gün sayısı bitki tohum verimi bakımından aynı özellikleri paylaştığı görülmüştür. *Vicia sativa* ve *Vicia cracca arasında* bin tane ağırlığı ve çiçeklenme gün sayısı bakımından benzerlik olduğu saptanmıştır. Sonuç olarak, geniş ölçekli ve kapsamlı olarak yürütülen agrocoğrafik araştırmanın sonuçları ve değerlendirilmesi sonucunda Trakya bölgesi doğal florasında Vicia cinsine ait çok sayıda yabani genotipin bulunduğu, Trakya bölgesinin *Vicia* sp. bakımından önemli biyoçeşitlilik potansiyeline sahip olduğu belirlenmiştir. Yabani fiğ türlerine ait genotiplerin tohumlarının çoğaltılması sonucunda devam edilecek adaptasyon çalışmalarıyla ümitvar hatların geliştirilmesi yanında uygun ıslah yöntemleri ile *Vicia sativa*, *Vicia pannonica* ve *Vicia villosa* türlerine ait ileri hatların ve çeşit adaylarının elde edilmesi mümkün olacaktır.

Yapılan değerlendirmeler sonucunda en uygun seleksiyon kriterlerinin sap çapı, bin tane ağırlığı ve bitki tohum verimi olduğu saptanmıştır.

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Original Article

Contribution to the Knowledge of the Acaenitinae and Diplazontinae (Hymenoptera: Ichneumonidae) fauna of Elazığ Province in Eastern Türkiye

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ABSTRACT

This study aimed to evaluate Ichneumonidae samples collected from Elazığ province, located in eastern Türkiye. At the end of the study, two species belonging to the subfamily Acaenitinae Förster, 1869 and one species belonging to the subfamily Diplazontinae Viereck, 1918 were identified and listed. Among these species, *Phaenolobus areolator* (Constantineanu & Constantineanu, 1968) has been recorded in the Eastern and Southeastern Anatolia Regions; *Phaenolobus fulvicornis* (Gravenhorst, 1829) in the Eastern Anatolia, Mediterranean and Black Sea Regions; and *Diplazon laetatorius* (Fabricius, 1781) across all regions of Türkiye. *Phaenolobus areolator* and *Phaenolobus fulvicornis* are relatively poorly known species in Türkiye, whereas *Diplazon laetatorius* is a widespread species. With this study, these species have been recorded from Elazığ Province fort he first time. In addition, information on the locality, collection date, host plant and distribution of each species in Türkiye provided.

Key words: Ichneumonidae, Acaenitinae, Diplazontinae, Elazığ, Türkiye

Türkiye'nin Doğusunda Yer Alan Elazığ İlinin Acaenitinae ve Diplazontinae (Hymenoptera: Ichneumonidae) Faunasına Katkılar

ÖZ

Bu çalışma, Türkiye'nin doğusunda yer alan Elazığ ilinden toplanan Ichneumonidae örneklerini değerlendirilmeyi amaçlamıştır. Çalışma sonucunda, Acaenitinae Förster, 1869 alt familyasına ait iki tür ve Diplazontinae Viereck, 1918 alt familyasına ait bir tür tanımlanmış ve listelenmiştir. Bu türler arasında, *Phaenolobus areolator* (Constantineanu & Constantineanu, 1968) Doğu Anadolu ve Güneydoğu Anadolu Bölgelerinde; *Phaenolobus fulvicornis* (Gravenhorst, 1829) Doğu Anadolu, Akdeniz ve Karadeniz Bölgelerinde ve *Diplazon laetatorius* (Fabricius, 1781) ise Türkiye'nin tüm bölgelerinde tespit edilmiştir. *Diplazon laetatorius* yaygın bir tür olmasına rağmen, *Phaenolobus areolator* ve *Phaenolobus fulvicornis* Türkiye'de nispeten az bilinen türlerdir. Bu çalışma ile bu türler Elazığ ilinden ilk kez kaydedilmiştir. Ayrıca her türün lokalitesi, toplanma tarihi, konukçu bitkisi ve Türkiye'deki dağılımı hakkında bilgi verilmiştir.

Anahtar kelimeler: Ichneumonidae, Acaenitinae, Diplazontinae, Elazığ, Türkiye.

INTRODUCTION

Ichneumonidae known as the ichneumon wasps, Darwin wasps, or ichneumonids is the largest Hymenoptera family (Giovanni et al., 2015) and a family of parasitoid wasps of Hymenoptera. Ichneumonidae one of the most diverse groups within the Hymenoptera with divided into 42 subfamilies with over 25.000 species currently described (Bennett et al., 2019). Besides having the highest endemism rates, this family is also highly relevant for the practice of biological control since the species that comprise it obligatorily deposit their eggs in

arthropods (Pádua et al., 2024). Although the members of the Ichneumonidae represent one of the most important groups of parasitoids for pest management is concerned, the researches on ichneumonid fauna of Türkiye were explored very restricted (Özbek et al., 2003).

The subfamily Acaenitinae is moderately large with 28 genera and about 280 species in the world (Yu et al., 2016). Most of the species are associated with forest. The hosts are different Coleoptera and conceivably Lepidoptera, boring in wood tissues (Sheng and Sun, 2014). Kolarov (1995), in his catalogue listed two species in five genera of the subfamily Acaenitinae occurring in Türkiye (Kolarov, 1989; Sedivy, 1958). Later, this number increased with the contributions of several authors (Çoruh and Kolarov, 2013; Çoruh et al. 2014; Çulcu, 2015; Doğru, 2022; Kolarov and Gürbüz, 2010; Kolarov et al., 2002).

Diplazontinae is a small to medium large subfamily of Ichneumonidae and comprises more than 23 genera and 350 species in the World (Yu et al., 2016). These subfamily members are koinobiont endoparasitoids of Syrphidae (Diptera). Oviposition is into the egg or larvae and adult emergence is occurs from the puparium of hosts (Shaw and Wahl, 1989). Diplazontinae is best generally represented in the Afrotropical, Australasian, Holarctic, Neotropical, Oceanic and Oriental Regions (Çoruh, 2011). Kolarov (1995), in his catalogue listed 10 species in 4 genera of the subfamily Diplazontinae occurring in Türkiye (Avcı ve Özbek, 1991; Düzgüneş, 1982; Erkin, 1983; Kolarov, 1989; Öncüer, 1991; Soydanbay, 1976, 1978; Tuatay et al., 1972), Since then several authors (Alaserhat and Güçlü, 2020; Anlaş et al., 2008; Buncukçu, 2008; Çoruh, 2011; Çoruh et al., 2014; Doğru, 2022; Duman et al., 2013; Eroğlu et al., 2011; Gülmez et al., 2021; Gürbüz, 2005; Gürbüz et al., 2008; Gürbüz et al., 2009a; Gürbüz et al., 2011; İnecikliоğlu, 1922; Kaplan, 2023; Kıraç, 2012; Kıraç and Gürbüz, 2020; Kolarov, 2015; Kolarov et al., 2017; Kolarov and Çalmaşur, 2011; Özdemir, 2001; Sarı and Çoruh, 2018; Yurtcan et al., 1999) have made valuable contributions to our knowledge of Diplazontinae fauna in Türkiye.

The purpose of this study is identify the Ichneumonidae (Acaenitinae and Diplazontinae) species collected from Elazığ Eastern of Türkiye, to make this data available to researchers and relevant people and to contribute the biodiversity.

MATERIALS AND METHODS

Adult specimens of Ichneumonidae were collected from Elazığ province, located in the west of the Eastern Anatolia Region of Türkiye (Figure 1). Akçakiraz is located in the southeast of Elazığ. Its altitude ranges from 880 m to 1100 m., it has a very mild structure compared to the typical continental climate. Sweeping nets were used to obtain samples on flowering plants. The collected specimens were killed with ethyl acetate and prepared and labeled according to taxonomic rules and regulations.

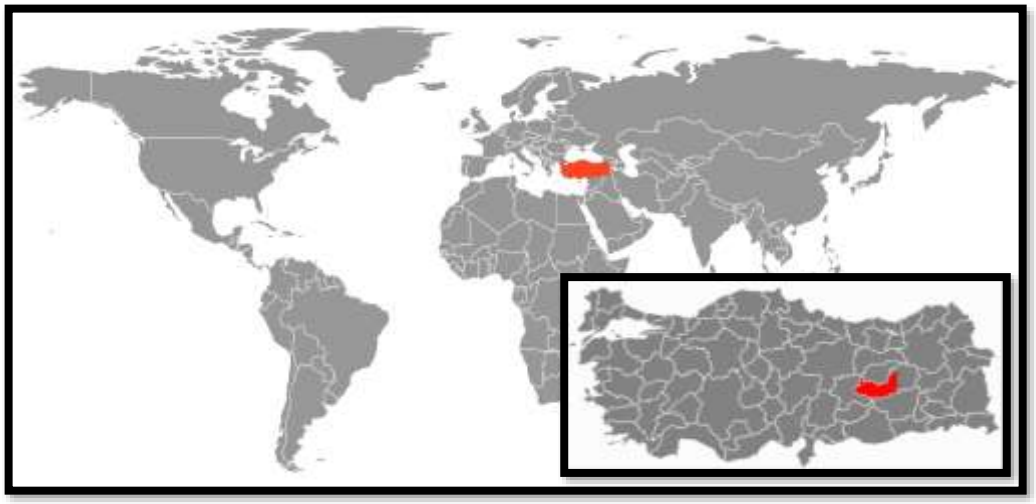

Figure 1. Location map of Elazığ Province.

The material is deposited in the collection of Department of Plant Protection, Faculty of Agriculture, Atatürk University (EMET). General geographic distribution and associated plants belonging to species were taken by Yu et al. (2016). The specimens were identified by Dr. Janko KOLAROV (Bulgaria).

RESULTS AND DISCUSSION

As a result of the study, three species belonging to the Ichneumonidae (Acaenitinae and Diplazontinae) family were determined. All of these species are the first record for Elazığ insect fauna.

Subfamily Acaenitinae Förster, 1869

Phaenolobus areolator (Constantineanu & Constantineanu, 1968)

Orginal name: *Moldacoenitus areolator.*

Identifier: *Moldacoenitus areolator* Constantineanu & Constantineanu, 1968

Materyal examined: TR: Elazığ, Akçakiraz, 38 36' 50.98" N, 39° 17' 20.99" E, 893 m, 19.V.2023, ♀, leg: Y. Bulak Korkmaz.

Hosts: Unknown.

Associate (plants): Unknown.

Distribution in Türkiye: Anatolia (Izquerdo, 1985; Kolarov, 1995); Erzurum, Kars, Şanlıurfa (Çoruh and Kolarov, 2013); Erzurum (Çoruh et al., 2014; Kolarov et al., 2002) (Figure 2a).

General Geographic Distribution: Palaearctic Region.

Remarks: New record for Elazığ.

Phaenolobus fulvicornis (Gravenhorst, 1829)

Original name: *Acoenites fulvicornis.*

Identifier: *Acoenites fulvicornis* Gravenhorst, 1829

Synonym history: *Collyria erythrogaster*.

Materyal examined: TR: Elazığ, Akçakiraz, 38 36' 50.98" N, 39° 17' 20.99" E, 893 m, 19.V.2023, ♂, leg: Y. Bulak Korkmaz.

Hosts: Coleoptera: *Phytoecia cephalotes* Küster, *Phytoecia coerulescens* (Scopoli).

Associate (plants): *Anthriscus sylvestris* (L.), *Heracleum sphondylium* L., (Apiaceae); *Salvia sylvestris* L. (Lamiaceae).

Distribution in Türkiye: Anatolia (Kolarov, 1995; Scaramozzino, 1986), Erzurum (Kolarov et al., 2002); Isparta (Gürbüz, 2005); Isparta (Gürbüz et al., 2009a); Adana, Isparta (Kolarov and Gürbüz, 2010); Artvin, Bayburt, Erzurum, Kars (Çoruh and Kolarov, 2013); Erzurum (Çoruh et al., 2014); Bayburt, Erzurum (Çoruh and Çalmaşur, 2016); Rize (Kolarov et al., 2016); Erzurum (Sarı and Çoruh, 2018) (Figure 2b).

General Geographic Distribution: Palaearctic Region.

Remarks: New record for Elazığ.

Subfamily Diplazontinae Viereck, 1918

Diplazon laetatorius (Fabricius, 1781)

Original name: *Ichneumon laetatorius.*

Identifier: *Ichneumon laetatorius* Fabricius, 1781

Synonym history: *Anomalon attractus*, *Bassus albovarius, Bassus balearicus, Bassus cinctipes; Bassus generosus, Bassus ikiti, Bassus senegalensis, Bassus sycophanta, Bassus terminalis, Bassus tripicticrus, Bassus venustulus, Ichneumon dichrous, Scolobates varipes.*

Materyal examined: TR: Elazığ, Akçakiraz, 38 36' 50.98"N, 39° 17' 20.99" E, 893 m, 19.V.2023, ♀, leg: Y. Bulak Korkmaz.

Hosts: There are 78 host information available for this species.

Associate (plants): *Baccharis pilularis* DC., *Cynara scolymus* L., (Asteraceae); *Citrullus lanatus* (Thunb.) (Cucurbitaceae); *Citrus sinensis* (L.) (Rutaceae); *Heracleum sphondylium* (Eltrot), *Peucedanum oreoselinum* (L.) (Apiaceae); *Listera ovata* (L.) (Orchidaceae); *Malus domestica* (L.) (Rosaceae); *Oryza sativa* (L.), *Poa pratensis* (L.), (Poaceae); *Picea excelsa* (Lam.) (Pinaceae); *Vicia faba* (L.) (Fabaceae).

Distribution in Türkiye: Ankara, İstanbul (Düzgüneş, 1982; Erkin, 1988; Kolarov, 1989; Öncüer, 1991; Soydanbay, 1976, 1978; Tuatay et al., 1972); Erzurum (Avcı and Özbek, 1991); Ankara, İstanbul (Kolarov, 1995); Edirne, Tekirdağ, Kırklareli, İstanbul (Yurtcan et al., 1999), Afyon, Ankara, Bolu, Burdur, Eskişehir, Isparta, Nevşehir, Konya (Özdemir, 2001); Isparta (Gürbüz, 2005); Adana (Buncukçu, 2008, Gürbüz et al., 2008); İzmir (Anlaş et al., 2009); Isparta (Gürbüz et al., 2009); Artvin, Erzincan, Erzurum, Trabzon, Şanlıurfa (Çoruh, 2011), Eskişehir (Eroğlu et al., 2011); Adana, Hatay, Osmaniye (Gürbüz et al., 2011); Erzincan (Kolarov and Çalmaşur, 2011); Denizli (Kıraç, 2012); Diyarbakır, Şanlıurfa (Duman et al., 2013); Erzurum (Çoruh et al., 2014); Adana, Adıyaman, Afyon, Aydın, Denizli, Erzincan, Erzurum, Isparta, İçel, Kahramanmaraş, Kırklareli, Muğla, Sinop, Zonguldak (Kolarov, 2015); Denizli (Kıraç and Gürbüz, 2020); Giresun (Kolarov et al., 2017); Erzurum (Sarı and Çoruh, 2018); Erzincan, Gümüşhane (Alaserhat and Güçlü, 2020); Adıyaman, Siirt (Gülmez et al., 2021); Edirne (Doğru, 2022; İneciklioğlu, 2022); Bingöl, Diyarbakır (Kaplan, 2023) (Figure 2c).

General Geographic Distribution: Nearctic, Neotropical, Oceanic, Oriental, Palaearctic Regions.

Remarks: New record for Elazığ.

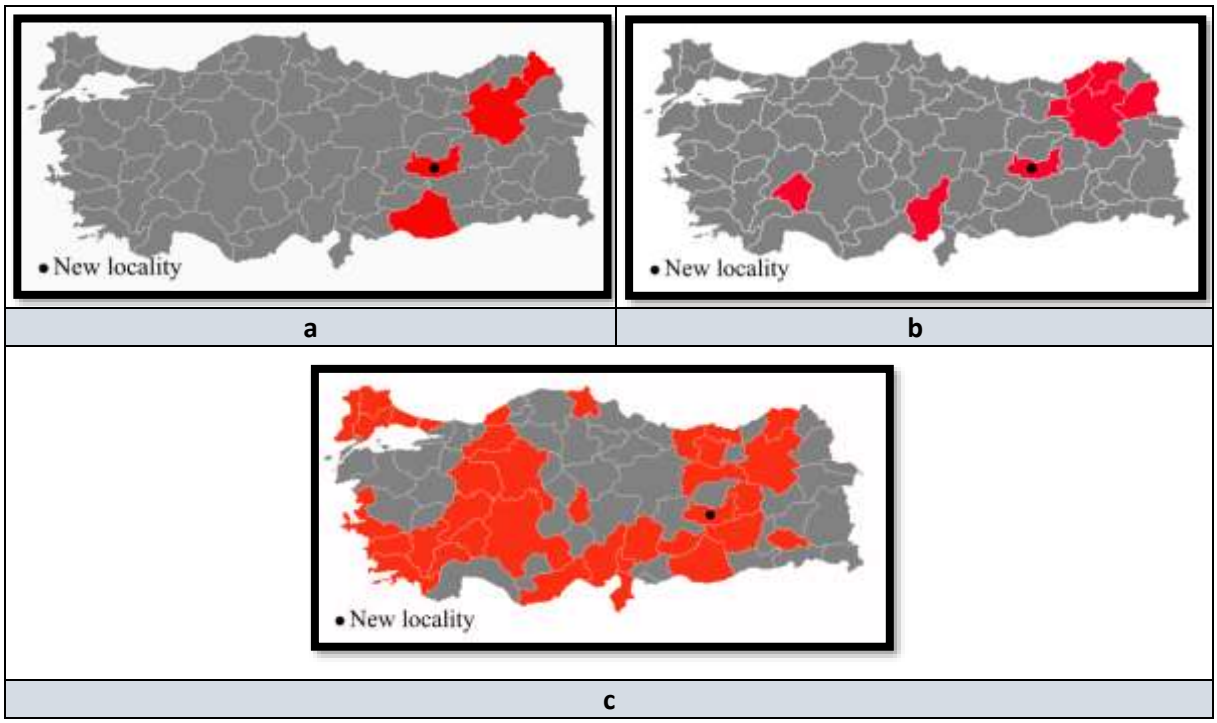

Figure 2. Distribution of Türkiye: a) *Phaenolobus areolator* (Constantineanu & Constantineanu, 1968), b) *Phaenolobus fulvicornis* (Gravenhorst, 1829), c) *Diplazon laetatorius* (Fabricius, 1781)

CONCLUSION

Türkiye, which can be found between three continents, hosts many and different insect and plant species due to its topographic geography and different climate types. Due to this structure of Türkiye, it is necessary and important to examine ichneumonids in terms of taxonomic and biodiversity. Although ichneumonids are very important parasitoid group, they have not been studied sufficiently in Türkiye. The number of species, which was 393 in 1995, reached approximately 460 in 30 years.

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Declaration of interests

The authors declare that they have no conflict of interest.

Author Contributions

Saliha ÇORUH: Conceptualization; data curation; formal analysis; methodology; software; writing— original draft; writing—review and editing.

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ÖZ

Buğday tek yıllık otsu bir bitkidir ve karasal iklim koşullarında yetişmektedir. Buğday; ekmek, makarna, bulgur, erişte vb. ürünlerin üretilmesi için kullanılmaktadır. Gerek dünya çapında gerekse ülkemiz için önemli olan buğday çeşitleri ıslah yoluyla elde edilmektedir. TAGEM'e (Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü) bağlı araştırma enstitüleri ıslah çalışmaları yapmaya ve ıslah edilen çeşidi tescil ettirmeye yetkilidir. Bu çalışmada üreticilerin TAGEM tarafından tescil edilen buğday çeşitlerinden memnuniyet durumları incelenmektedir. Çalışmada ilk olarak buğdayın dekara verimini etkileyen kriterler araştırılmış ve regresyon analiziyle test edilmiştir. Dekara verimini etkileyen kriterler; sulama sayısı, soğuğa dayanıklılık, taban gübresi kullanma durumu ve üst gübresi kullanma durumudur. Analiz sonucuna göre dekara verim ve bu verimi etkileyen kriterler arasında anlamlı sonuç çıkmış olup sulama sayısı, soğuğa dayanıklılık, taban gübresi kullanma durumu ve üst gübresi kullanma durumu verimliliği arttırmaktadır. Buğday üreticilerinin üretimini gerçekleştirdiği buğday çeşitlerinden memnun olup olmama durumu lojistik regresyon analizi ile test edilmiştir. Lojistik regresyon analizi sonucunda üreticilerin tercih edilen buğday çeşidinden memnun olma durumunu etkileyen faktörler istatistiki olarak tercih edilen çeşidin hastalığa dayanaklı olması, yöre iklimine uygunluğu ve çeşidin kalitesi ile anlamlı olarak elde edilmiştir. Sonuç olarak Adana, Mersin Kahramanmaraş ve Sivas illerinde TAGEM tarafından tescil edilen buğday çeşitlerini kullanan üreticilerin bu çeşitlerden memnun olduğu belirlenmiştir. Ancak çeşidin kalitesi, hastalığa dayanıklılık ve iklime uygun çeşitlerin geliştirilmesi gerekliliği vardır. Ürün kalitesine etkisi yüksek olan sulama sayıları ile ilgili alt yapısı uygun bölgelerde sulama alt yapıları oluşturularak, sulama faaliyetlerinin daha etkin hale getirilmesi için eğitimler düzenlenmesinde fayda vardır.

Anahtar kelimeler: Ürün, Islah,Tercih

Evaluation of Wheat Varieties Developed by General Directorate of Agricultural Research and Policies (TAGEM) from the Perspective of Producers; Kahramanmaraş, Mersin, Adana and Sivas Province Example

ABSTRACT

Wheat is an annual herbaceous plant and wheat grows in continental climate conditions. Wheat is used to produce products like bread, pasta, bulgur, noodles etcWheat varieties that important both worldwide and our country are obtained through breeding. Research institutes affiliated with TAGEM (General Directorate of Agricultural Research and Policies) are authorized to carry out breeding studies and register the improved variety. In this study, the satisfaction status of producers with wheat varieties registered by TAGEM is examined. In the study, firstly, the criteria affecting the yield of wheat per decare were investigated and tested with regression analysis. The criteria affecting the yield per decare are number of irrigations, resistance to cold, use of bottom fertilizer and use of top fertilizer. According to the analysis results, a significant result was found between the

yield per decare and the criteria affecting this yield, and the number of irrigations, resistance to cold, use of bottom fertilizer and use of top fertilizer increase the productivity. Whether wheat producers are satisfied with the wheat varieties that they produce was tested with logistic regression analysis. As a result of logistic regression analysis, the factors affecting the satisfaction of the producers with the preferred wheat variety were statistically significant as the disease resistance of the preferred variety, suitability for the local climate and quality of the variety. As a result, it was determined that the producers using the wheat varieties registered by TAGEM in Adana, Mersin Kahramanmaraş and Sivas provinces were satisfied with these varieties. However, there is a need to develop varieties that are suitable for the quality of the variety, disease resistance and the climate. Training can be organized to develop irrigation activities more effectively by establishing irrigation infrastructures in regions with suitable infrastructure regarding irrigation numbers that have a high impact on product quality.

Key words: Product,Reclamation,Choice

GİRİŞ

Buğday tek yıllık otsu bir bitkidir ve karasal iklim koşullarında yetişmektedir. Un, hayvan yemi gibi ürünlerin üretiminde kullanılmaktadır ve insan uygarlığının temelini oluşturmaktadır. İlk buğday ekimi; yaklaşık 10.000 yıl önce avcılık ve toplayıcılıktan yerleşik tarıma geçişin yaşandığı Neolitik Devrim'in bir parçası olarak gerçekleşmiştir (Shewry, 2009). Günümüzde ise buğday, çok çeşitli iklim koşullarında ve birçok coğrafi bölgede 220 milyon hektardan fazla alanda en yaygın olarak yetiştirilen tahıldır (Shiferaw vd., 2013).

Dünyada tahıl üretimi 4.766.323.000 hektar alanda yapılmaktadır. Tahıl üretim miktarı ise 8.756.091,18 tondur (FAO, 2022). Buğday ise yılda 600 milyon tondan fazla hasat edilen "üç büyük" tahıl ürünü arasında sayılmaktadır (Anonim, 2016). FAO 2022 verilerine göre dünyada buğday üretimi 242.675.832 hektar alandır. Buğday üretim miktarı ise 946.167.568,19 tondur. Türkiye'de buğday üretimi 6.601.805,00 hektar alanda yapılmaktadır (FAO, 2022). Buğday miktarı ise 19.750.000 tondur (FAO, 2022). Türkiye'de tahıllar bitkisel üretimin %54,3'ünü oluşturmaktadır (TÜİK, 2023). Buğday üretimi ise tahılların %28,3 'ünü oluşturmaktadır (TÜİK, 2023). TÜİK verilerine bakıldığında bitkisel üretimin yarısından fazlasını tahıllar, tahılların içinde de önemli bir kısmını buğday oluşturmaktadır. Söz edilen verilere göre buğday Türkiye için önem arz eden bir üründür. Türkiye için buğday sadece sayısal verilerle değil kültürel anlamda da önemlidir.

Buğday; ekmek, makarna, bulgur, erişte vb. ürünlerin üretilmesi için kullanılmaktadır. Buğdaydan elde edilen bu ürünler Türkiye'de beslenmenin önemli bir kısmını oluşturmaktadır. Gerek dünya çapında gerekse ülkemiz için önemli olan buğday çeşitleri ıslah yoluyla elde edilmektedir. Sürekli artan nüfusla birlikte buğday verimine yönelik talep 2050 yılına kadar %60 artacak bu da yılda ortalama %2'lik artış anlamına gelmektedir (Li vd., 2023). Verimli, hastalıklara ve zararlılara dayanıklı, kuraklığa, soğuğa ve yüksek sıcaklıklara dayanıklı buğday çeşitleri geliştirmek için ıslah çalışmaları yapılmaktadır. Türkiye'de buğday ıslah çalışmaları Cumhuriyetin ilk yıllarından itibaren yapılmaktadır. Tüm dünyada olduğu gibi Türkiye'de de modern buğday çeşitlerini geliştirme çalışmaları 1960'lı yıllarda hız kazanmıştır (Anonim, 2016). Ülkemizde ıslah edilmiş çeşitlerin sertifikalandırılması ve tescillenmesi Tohumluk Tescil Sertifikasyon Merkez Müdürlüğü tarafından yapılmaktadır. Buğday çeşidi tescil ettirmeye yetkili kuruluşlar TAGEM'e bağlı araştırma enstitüleri, özel sektör, üniversiteler, Tarım İşletmeleri Genel Müdürlüğü (TİGEM) ve gerçek kişilerdir. Buğday çeşitleri ekmeklik ve makarnalık olarak sınıflandırılmaktadır. Milli çeşit listesine göre Türkiye'de tescillenen ekmeklik buğday çeşidi sayısı 433 adet, makarnalık buğday çeşidi sayısı ise 105 adettir. TAGEM'e bağlı araştırma enstitüleri 49 adet olup bunlardan 10 adedi merkez araştırma enstitüsü, 13'ü bölgesel araştırma enstitüsü ve 26'sı konu araştırma enstitüsüdür. Tescilli buğday çeşidinde TAGEM'e bağlı araştırma enstitüleri ön plana çıkmaktadır. TAGEM'e bağlı enstitüler tarafından geliştirilen makarnalık ve ekmeklik buğday çeşidi sayısı 194'tür.

Bu çalışmada yer alan illerden 2022 verilerine göre Kahramanmaraş'ta buğday ekilen ve hasat edilen alan 954.134 da'dır. Üretilen buğday miktarı 325.131 ton 'dur. Buğdaydan alınan verim ise 341 kg/da'dır. Adana'da hasat edilen buğday alanı 1.397.811 da'dır. Buğday miktarı 537.941 ton ve alınan verim ise 385 kg/da'dır. Mersin'de hasat edilen buğday alanı 696.244 da'dır. Buğday miktarı 188.166 ton ve birim alandan alınan verim ise 270 kg/da'dır. Sivas'ta hasat edilen buğday 2.221.547 da'dır. Buğdaydan alınan verim 243 kg/da ve üretim miktarı 539.189 tondur (TÜİK, 2024).

Literatürde buğday üretimi ve pazarlama süreçlerini ele alan çeşitli çalışmalar dikkat çekmektedir. Taşcı ve diğerleri (2023), demografik özelliklerin buğday çeşit seçimindeki etkisini analiz ederken, özellikle kılçıklı ve kılçıksız buğday tercihi ile bölgedeki domuz varlığı arasındaki ilişkiye vurgu yapmıştır. Bu durum, hem ekolojik hem de sosyal faktörlerin tarımsal karar alma süreçlerindeki önemini göstermektedir. Benzer şekilde, Engin ve diğerleri (2022) demografik özelliklerin çok amaçlı politikalar ve beklentiler üzerindeki etkisini tartışmış ve bu bağlamda üreticilerin bireysel önceliklerinin politika oluşturulmasında nasıl dikkate alınması gerektiğini vurgulamıştır.

Taşcı vd. (2022), üreticilerin buğday çeşit seçiminde rol oynayan faktörleri incelerken, üretim maliyeti ve pazarlama koşulları gibi ekonomik etkenlerin önemini ortaya koymuştur. Bu bağlamda, Özer ve Dal'ın (2022) çiftçi memnuniyeti ve beklentilerine odaklanarak, memnuniyetin artırılması için politika yapıcıların dikkate alması gereken unsurlara ışık tutması dikkat çekicidir. Öte yandan, pazarlama davranışlarını inceleyen Tarhan ve Dellal'ın (2021) çalışması, çiftçilerin pazarlama stratejilerini şekillendiren dışsal faktörlere odaklanmış, bu faktörlerin üretici davranışlarını nasıl etkilediğini göstermiştir. Koçer ve Konuşkan (2020), mısır ve buğday üreticilerinin sorunlarını ele alırken, demografik özelliklerin bu sorunların niteliğini şekillendirdiğini belirtmiştir. Demografik özelliklerin önemi, Taşcı vd. (2020) tarafından makarnalık buğday üretim ve pazarlama yapılarında da görülmüş, bu çalışmada üreticilerin ekonomik ve teknolojik uyum becerileri değerlendirilmiştir. Tarımsal desteklerin memnuniyete etkisini ele alan Özgür (2018), desteklerin üretim motivasyonunu artırdığına dikkat çekmiş ve bu bulgular, Hameed, Hassan ve Jaber'in (2017) tohum üreticilerinin memnuniyet düzeyi üzerine yaptığı çalışmalarla paralellik göstermektedir. Teknolojik ve ekonomik faktörlerin yanı sıra, Taşcı ve Oğuz (2014) buğday üretim maliyetlerini ve teknoloji kullanım düzeyini incelerken, teknolojik gelişmelerin tarımsal verimlilik üzerindeki etkisini tartışmıştır. Toplulaştırma gibi yapısal reformlara ilişkin üretici algılarını inceleyen Altıntaş ve Akçay (2009), bu reformların üreticiler üzerindeki etkisinin sosyo-ekonomik bağlamda değerlendirilmesi gerektiğini vurgulamıştır. Son olarak, Buguk'un (2001) buğday alıcı ve satıcılarının kararlarını etkileyen faktörleri ele alan çalışması, tarım piyasalarında karar alma süreçlerinin karmaşıklığını ortaya koymaktadır.

Bu çalışmalar genel olarak, demografik, ekonomik, teknolojik ve çevresel faktörlerin tarımda hem üretim hem de pazarlama süreçlerini nasıl şekillendirdiğine dair önemli ipuçları sunmaktadır. Ancak bu bulgular, uygulamada politika yapıcılar ve üreticiler arasındaki etkileşimlerin daha yakından değerlendirilmesini gerektirmektedir. Bu bağlamda, literatürün sunduğu bulguların birbirleriyle ilişkili olduğunu ve farklı bağlamlarda birbirini desteklediğini söylemek mümkündür. Literatür incelendiğinde buğday üretiminde dekara ortalama verimi etkileyen faktörler ve buğday çeşidinden memnuniyet durumu üzerine yapılan çalışmaların yetersiz olduğu gözlemlenmiştir. Bu çalışma üreticilerin TAGEM tarafından tescil ettirilen buğday çeşitlerinden öncelikli beklentilerini araştırmış olup, memnuniyet durumlarını incelemiştir. Bu yönüyle literatüre önemli katkı sağlayacak, TAGEM bünyesinde çalışan araştırmacılara üreticilerin fikirlerine yönelik bilgi sunacaktır.

MATERYAL ve METOT

Bu araştırma sonuçları, TAGEM tarafından desteklenen "TAGEM Tarafından Geliştirilen Buğday Çeşitlerinin Üretici Memnuniyeti Açısından Değerlendirilmesi ve Takibi Adana, Mersin, Kahramanmaraş, Sivas İli Örneği" isimli projeden, Orta Anadolu'da yer alan Sivas ili ve Doğu Akdeniz Bölgesinde yer alan Kahramanmaraş, Adana ve Mersin illerinde buğday üretimi yapan tarım işletmelerinden elde edilen verilerden üretilmiştir.

Örneklem büyüklüğü için kartopu örnekleme ve zincirleme yöntemi kullanılmıştır. Kartopu örnekleme yöntemi; araştırmacı öncelikle bir grup bireyler belirler ve bu bireylerle görüşür ve sonrasında bu bireylerderden yeni bireyler önermesini ister böylece örneklem giderek genişler ve büyür (Goodman, L. A., 1961) Bu yöntemin kullanılma sebebi evren büyüklüğünün bilinmemesi ve TAGEM çeşitlerini üreten üreticilerin kayıtlarının olmamasıdır. Anketler, 2022 yılında Kahramanmaraş, Sivas, Adana ve Mersin illerine ait hasat zamanında yüz yüze görüşülerek yapılmıştır. Anketlerin yapıldığı il, ilçe ve anket sayıları Tablo 1'de gösterilmektedir.

Tablo 1. Araştırma alanına göre anket sayıları dağılımı

İller	İlçeler	Anket Sayısı	%
Mersin	Tarsus	44	14,5
Adana	Sarıçam, İmamoğlu, Ceyhan	77	25,3
Kahramanmaraş	Afşin, Elbistan, Göksun, Ekinözü	59	19,4
Sivas	Gemerek, Hafik, Kangal, Merkez, Şarkışla, Yıldızeli	124	40,8

Demografik özellikler tanımlayıcı istatistiklerle elde edilmiştir. Üreticilerin dekara aldıkları verimi etkileyen faktörler regresyon modeli ile test edilmiştir. Modelde bağımlı değişken dekara ortalama buğday verimidir. Bu verimi etkileyen bağımsız değişkenler; sulama sayısı, soğuğa dayanıklılık, taban gübresi kullanma durumu ve üst gübresi kullanma durumudur. Memnuniyeti etkileyen değişkenler arasındaki ilişkiler için çapraz korelasyon analizi yapılmıştır (Jevsnik vd., 2008). TAGEM tarafından geliştirilen buğday çeşitlerini tercih eden ve üretimini gerçekleştiren üreticilerin buğday çeşidinden memnun olup olmama durumu kategorik değişken (evet-hayır) sorgulamasından dolayı lojistik regresyon analizine tabi tutulmuştur. Analizdeki bağımsız değişkenler; çeşit ilgili hastalığa dayanaklı mı?, yöre iklimine ve toprak yapısına uygun mu?, zararlılara dayanaklı mı?, kuraklığa dayanaklı mı?, soğuğa dayanaklı mı?, kaliteli mi?, çeşit için pasla mücadele yaptınız mı?, süne mücadelesi yaptınız mı?, yabancı ot ilacı kullandınız mı?, sap-samandan memnun oldunuz mu? sorularından oluşmaktadır. Kategorik değişkenlerde soru cevapları evet-hayır şeklinde alınmıştır.

Analizde kullanılan model: $Y= \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 +...+ \beta_nX_n + \epsilon$ şeklinde kurulmuştur.
Y bağımlı değişkeni temsil etmektedir.
$X_1, X_2, X_3, \ldots, X_n$ bağımsız değişkenlerdir.
β_0 y-intercept (kesim noktası) terimidir.
$\beta_1, \beta_2, \beta_3, \beta_4$ bağımsız değişkenlerin katsayılarıdır.
ϵ hata terimidir.

Bu model, bağımsız değişkenlerin bağımlı değişken üzerindeki etkisini belirlemek için kullanılır. Modelde yer alan katsayılar (β\betaβ) genellikle verilerden tahmin edilir ve bu tahminler, bağımsız değişkenlerdeki değişimlerin bağımlı değişken üzerindeki etkisini gösterir.

BULGULAR ve TARTIŞMA

Buğday üretiminin bir dönemi üretici elinde toprak hazırlığı ile başlar, tohumluk temini, ekim, bazı arazilerde sulama, gübreleme, hastalık ve zararlılarla mücadele, hasat, nakliye ve ürünün pazarlanması ile son bulur. Tüm bu sürecin başarısı üreticinin buğday üretimi memnuniyetini belirler. Bu süreçte yaşanan memnuniyet ise buğday üreticisinin gelecek yıllardaki üretiminin şeklini ortaya koyar ve üretimin sürdürülebilirliğinin temel taşıdır. Bu anlamda da şüphesiz ki üreticinin en büyük amacı başarılı bir üretim dönemi geçirmektir. Bu çalışmanın yapıldığı Adana, Mersin, Kahramanmaraş ve Sivas illerinde bu durum tam anlamı ile gerçekliğini korumaktadır. Bölgedeki üreticilerin her yıl ekim ayı sonu ve kasım ayının ilk haftası itibariyle üretim için gerekli kültürel işlemleri yaparak buğday ekimini gerçekleştirdiği görülmektedir. Buğdayın büyüme dönemlerinin Akdeniz iklimine sahip olan Adana, Mersin ve Kahramanmaraş'ın merkez ve merkeze bağlı ilçelerinde ekimden hasata kadar olduğu gözlemlenirken, sert karasal iklimin yaşandığı Adana'nın ve Kahramanmaraş'ın kuzey ilçeleri ve Sivas ilinin tamamımda buğday büyüme dönemlerinin ilkbahar döneminde başladığı görülmüştür. Hasat illerde görülen iklim yapısı ile benzerlik gösterip Adana-Mersin illerinde mayısın ilk haftası ile başlarken kademeli olarak artarak ağustosun ikinci haftası ile Sivas ilinin Yıldızeli ilçesinde son bulmaktadır. Bulgular bakımından değerlendirildiğinde, iklimsel faktörlerin buğday üretimi üzerinde oldukça etkin olduğu görülmektedir. Akdeniz ikliminin hakim olduğu bölgede buğday büyüme zamanlarının ekimden hasata kadar yayılması buğday üretimi açısından oldukça önemli olduğunu göstermektedir. Karasal iklimin hakim olduğu bölgelerde ise büyüme bahar dönemlerine kaymakta, ürün kış dönemini dinlenme evresi olarak geçirmektedir. Bu durumun sonucu olarakta farklı iklim bölgelerinde üreticiler tarafından farklı buğday çeşitlerinin tercih edildiği ortaya çıkmaktadır. Daha önceki çalışmalara bakıldığında Kassie vd. (2015) göre de akdeniz ikliminin hakim olduğu bölgelerde sert karasal iklimin hakim olduğu bölgelere göre daha düzenli üretim dönemlerinin olduğu ortaya konulmuştur. Bu çalışmada yukarıda bilgisi verilen iller de bu üretim dönemini gerçekleştiren üreticilerle görüşülmüş elde edilen bulgular aşağıda gösterilmiştir.

Demografik Özellikler

Ankete katılan üreticilerin yaş ortalamaları her il bazında ayrı ayrı ve genel olarak gösterilmiş olup, yaş ortalaması en yüksek il Adana'dır (51,7). Yaş ortalaması en düşük il ise Kahramanmaraş'tır (47,6). İllerin genel yaş ortalaması 49,3 olup, illerin yaş ortalamalarının birbirine oldukça yakını olduğu gözlenmektedir. Bu sonuçlar literatürlerle benzerlik göstermektedir.

Tablo 2. Üreticilere ait demografik özellikler

İller	Yaş Ortalaması	Standart Sapma	Min Yaş	Max Yaş	Okuryazar ve Okuma Yazma Bilmeyenler (%)	İlkokul (%)	Ortaokul ve Lise (%)	Lise Üstü (%)	Köy (%)	Mahalle (%)	İlçe (%)	İl (%)
Adana	51,7	14,60	22	87	2,6	48,7	39,5	9,2	84,2	1,3	14,5	
Mersin	50,6	12,36	25	85	-	52,2	41,3	6,5	82,6	2,2	13	2,2
Kahramanmaraş	47,6	13,28	27	76	3,4	46,6	34,5	15,5	62,1	5,2	32,8	
Sivas	48,0	13,35	16	71	42,3	14,7	33,3	9,7	68,3	0,8	10,6	20
İller Ortalaması	49,3	13,56	16	87	21,7	33,9	35,2	9,2	75,1	1,9	16,2	6,7

Ankete katılan buğday üreticilerinin (TAGEM tarafından geliştirilen buğday çeşitlerini kullananlar) eğitim durumlarına bakıldığında, Adana (%48,7), Mersin (%52,2) ve Kahramanmaraş'ta (%46,6) en çok ilkokul mezunları tarafından buğday üretimi gerçekleştirildiği görülürken, Sivas'ta bu oran (%42,3) ile okuryazar olan üreticilere aittir. Öte yandan Sivas ilinde üniversite ve üstü mezunu olan buğday üreticisi oranı (%9,7) en düşükken, bu oran Kahramanmaraş'ta (%15,5) en yüksek olarak görülmektedir. Genel hatları ile üreticilerin sahip oldukları eğitim bakımından yoğunluğun ilkokul, ortaokul ve lise dengine dağıldığı gözlemlenmektedir (Tablo 2).

Araştırmada yer alan ve TAGEM tarafından geliştirilen buğday çeşitlerini kullanan üreticilerin en az altı ay ve üstü ikamet ettiği yerler baz alındığında iller itibariyle üreticilerin yaklaşık olarak %75'i köy ve çevresinde yaşadıklarını belirtmişlerdir. Bu durumda üreticilerin üretimini gerçekleştirdiği ürünün ikamet alanlarına yakın olduğunu göstermektedir. Ancak Kahramanmaraş ve Adana illerinde üretim yapan buğday üreticilerinin bu şehirlerin büyükşehir olması ve konaklama itibariyle merkez ilçelere bağlı mahallelerde olmasına karşın, üreticilerin hala ikametini köy olarak bildirilmesi bu iki şehir için köy ve mahallelerin birlikte değerlendirilebileceği durumunu da ortaya koymaktadır. Literatüre bakıldığında; Vural vd. (2024) 'ne göre köyde yaşayan üreticilerin ortalaması %74,7 olup bu çalışmayla benzerlik göstermektedir (Tablo 2).

Ankete katılan üreticilerin çiftçilik deneyim süreleri değerlendirilmiş olup, illerdeki üreticilerin genel deneyim ortalamasının yıl olarak 30,4 olduğu tespit edilmiştir (Tablo 3). İllerin deneyim süresi olarak çok farklılık göstermeyip benzer niteliktedir. Ayrıca ankete katılan buğday üreticilerin ortalama yaşlarının 49,3 olduğu düşünüldüğünde, üreticilerin 30 yıl deneyim ortalamasına sahip olması, üreticilerin çiftçiliğe erken yaşta başladığı ve bu anlamda tecrübeli olduklarını göstermektedir. Öte yandan Lökçü, Öğüt Yavuz ve Duru (2020)'ya göre yaş arttıkça deneyim süresinin artması çalışmada elde edilen sonuçlarla paralellik göstermektedir. Bu sonuçta çıkan sonuçları desteklemektedir.

Tablo 3. Üreticilerin çiftçilik deneyimleri (%)

İller	%	Ortalama	Standart sapma	Min	Max
Adana	25,1	32,53	14,06	5,0	65,0
Mersin	15,2	32,04	14,07	5,0	70,0
Kahramanmaraş	19,1	28,00	13,50	1,0	61,0
Sivas	40,6	29,62	14,33	1,0	60,0
GENEL	100,0	30,41	14,10	1,0	70,0

Araştırmada buğday üretimi yapan işletmelerin bitkisel üretimin yanında hayvancılık faaliyetini gerçekleştirip gerçekleştirmeme durumu incelenmiş (Tablo 4), tüm iller bazında araştırmaya katılan üreticilerin büyük çoğunluğunun bitkisel üretim ile hayvancılık faaliyetini bir arada devam ettirdikleri belirlenmiştir. Bu oranlar sırası ile Adana'da (%67,1), Mersin'de (%84,8), Kahramanmaraş'da (%62,1) ve Sivas'da (%66,9) olarak görünmektedir.

Tablo 4. Ankete katılan üreticilerin bitkisel üretimle birlikte hayvancılık yapma durumu

İller	Var	Yok	Toplam
Adana	32,9	67,1	100,0
Mersin	15,2	84,8	100,0
Kahramanmaraş	37,9	62,1	100,0
Sivas	37,7	62,3	100,0
Tüm iller	33,1	66,9	100,0

Buğday Çeşitleri Tercihi Memnuniyet Durumu

Araştırmanın yapıldığı iller bakımından buğday çeşit tercihleri belirlenmiş olup, üreticilerin buğday çeşidi tercihlerinin, şehirlerin sahip olduğu iklimsel ve bölgesel farklılıklarla ilişkili olduğunu göstermektedir. Bu anlamda Adana ve Mersin illeri için üretimi yapılan TAGEM tarafından geliştirilen buğday çeşitlerinin benzerlik gösterirken, daha çok sert karasal iklimin yaşandığı Sivas, Adana'nın kuzey ilçeleri ve Kahramanmaraş'ın kuzey ilçelerinde aynı çeşitlerin tercih edildiği görülmekte. Adana ve Mersin illerindeki üreticilerin neredeyse tamamına yakınının (%95) Adana-99 buğday çeşidini tercih ettiği görülürken, Kahramanmaraş'ta üreticilerin %60,3'ünün makarnalık buğday çeşidi olan Eminbey buğday çeşidini tercih ettikleri belirlenmiştir. Diğer çeşitlerin oranlarınım ise oldukça düşük olduğu gözlemlenmiştir. Sivas ilinde ise üreticilerin tercih eğilimi iki buğday çeşidi üzerinde yoğunlaşmıştır. Bunlar sırası ile makarnalık buğday çeşidi Kızıltan 91 (%51,2) ve Bayraktar 2000 buğday çeşididir (%36,6) (Tablo 7). Öte yandan Adana'da ankete katılan üreticilerin Ceyhan-99, Adana-99 ve Tekin çeşitlerini tercih ettikleri gözlemlenirken, Mersin ilinde Adana-99, Yakamoz ve Koç 2015 çeşitleri tercih edilmiştir. Kahramanmaraş ve Sivas'ta ise çeşitlilik artmıştır. Kahramanmaraş'ta Kızıltan 91, Çeşit-1252, Eminbey, Kunduru 1149, Bayraktar 2000, İmren ve Polathan çeşitleri tercih edilirken, Sivas'ta buğday üreticileri tarafından Kızıltan 91, Tosunbey, Çeşit-1252, Ekiz ve Reis çeşitleri tercih edilmiştir. Genel anlamda Adana ve Mersin'de ekmek buğday çeşidi tercih edilirken Kahramanmaraş ve Sivas illerinde makarnalık buğday çeşidi tercih edilmiştir.

Tablo 5. Ankete katılan bireylerin iller itibariyle tercih ettikleri buğday çeşitleri

İller	Çeşitler	Frekans	%
Adana	Adana-99	73	96,1
	Ceyhan-99	2	2,6
	Tekin	1	1,3
	Toplam	76	100,0
Mersin	Adana-99	43	93,5
	Yakamoz	2	4,3
	Koç 2015	1	2,2
	Toplam	46	100,0
Kahramanmaraş	Eminbey	35	60,3
	Çeşit-1252	6	10,3
	Kunduru 1149	6	10,3
	Kızıltan 91	5	8,6
	İmren	4	6,9
	Bayraktar 2000	1	1,7
	Polathan	1	1,7
	Toplam	58	100,0
Sivas	Kızıltan 91	63	51,2
	Bayraktar 2000	45	36,6
	Ekiz	8	6,5
	Tosunbey	3	2,4
	Çeşit-1252	2	1,6
	Reis	1	0,8
	Gerek 79	1	0,8
	Toplam	123	100,0

Buğday üreticilerinin (TAGEM tarafından geliştirilen buğday çeşitlerini kullanan) dekara verimini etkileyen kriterler araştırılmış ve regresyon analiziyle test edilmiştir. Analizde kullanılan bağımlı değişken; dekara ortalama buğday verimi olarak belirlenmiştir Dekara ortalama buğday verimini etkileyen bağımsız değişkenler; sulama

sayısı, soğuğa dayanıklılık, taban gübresi kullanma durumu ve üst gübresi kullanma durumudur. Değişkenler arasındaki ilişki regresyon testinin uygunluğu için korelasyon analizine tabi tutulmuştur. Yapılan analizde bağımlı değişkenle bağımsız değişkenler arasında orta düzey bir ilişki varken, bağımsız değişkenler arasında zayıf bir ilişki olduğu belirlenmiştir (Tablo 7).

Tablo 6. Ortalama dekara buğday verimi, sulama sayısı, soğuğa dayanıklılık, taban gübresi kullanımı ve üst gübre kullanımıyla ilgili tanımlayıcı özellikler

Göstergeler	Ortalama dekara buğday verim miktarı	Dönem içi sulama sayısı	Çeşidin soğuğa dayanıklılık durumu	Taban gübresi kullanma durumu	Üst gübre kullanma durumu
	(Kg/Da)	(Adet)	(1 Evet) (2 Hayır)	(Kg/Da)	(Kg/Da)
Ortalama	402,16	1,88	1,24	22,73	29,68
Std. Sapma	195,53	0,98	0,43	8,16	17,23

Tablo 7. Ortalama dekara buğday verimi sulama sayısı, soğuğa dayanıklılık, taban gübresi kullanımı ve üst gübre kullanımıyla ilgili korelasyon analizi

Değişkenler	Ortalama buğday verim miktarı	Sulama sayısı	Soğuğa dayanaklı mı	Taban gübresi kullanma	Üst gübre kullanma
Ortalama buğday verim miktarı	1				
Sulama sayısı	,527** (0,000)	1			
Soğuğa dayanaklılık	-,068** (0,005)	-0,032 (0,307)	1		
Taban gübresi kullanma durumu	,527** (0,000)	,579** (0,000)	-0,018 (0,397)	1	
Üst gübre kullanma durumu	,520** (0,000)	,503** (0,000)	-0,039 (0,074)	,603** (0,000)	1

önem derecesi; * : 0 .01 ≤ P≤ 0.05; ** : 0.001 ≤ P≤ 0.01

Dekara ortalama buğday verimliliği buğday üretimi için gerekli olan birçok faktör ile regresyon analizine sokulmuş olup analiz uygunluğunu sağlayan bağımsız değişkenler sulama sayısı, soğuğa dayanıklılık, taban gübresi kullanma durumu ve üst gübresi kullanma durumu ile test edilmiştir. Uygunluğu sağlamayan ve anlamlı bulunmayan değişkenler modelden çıkarılmıştır.

Yapılan analizde anlamlılık düzeyi (significance = P<0.05) olduğundan kurulan regresyon analizi anlamlı bulunmuştur (Tablo 8). Bu sonuca göre; sulama sayısı, soğuğa dayanıklılık durumu, taban gübresi kullanma durumu ve üst gübresi kullanma durumu bağımlı değişken dekara ortalama verim üzerinde anlamlı bir etkisi bulunmaktadır (P=0.000<0.05). Yapılan analiz sonucu bağımlı değişken olan dekara ortalama verimin %52'sinin modelde yer alan bağımsız değişkenler tarafından açıklandığını göstermektedir. Modelde yer alan β katsayıları incelendiğinde sulama sayısı artıkça, dekara buğday verimliği de artmaktadır (β = 0,58). Ayrıca soğuğa karşı dayanaklılık (β = 0,17), taban gübresi kullanıp kullanmama durumu ile ilgili kullananlarda verimliğin arttığı (β = 0,15) ve üst gübre kullananlarda verim artışı olduğu belirlenmiştir (β = 0,29).

Tablo 8. Buğday üretimindeki bazı girdilerin dekara verimliği üzerine regresyon analizi

Bağımsız değişken	Birim	Bağımlı Değişken	B	Std. Hata	β	t	P
Sabit				95,93		1,84	0,05
			176,32				
Sulama sayısı	Sayı		127,40	16,19	0,58	7,87	0,00**
Soğuğa dayanaklılık	Birim	Dekara verim	94,54	41,49	0,17	2,28	0,02*
Taban gübresi Kullanımı	Kg/Da		4,82	2,59	0,15	1,86	0,05
Üst gübre Kullanımı	Kg/Da		3,89	1,09	0,29	3,58	0,00**
				R=0,721	R2=0,52	F=25,14	P=0,000

önem derecesi; * : 0 .01 ≤ P≤ 0.05; ** : 0.001 ≤ P≤ 0.01

Ankete katılan buğday üreticilerinin üretimini gerçekleştiğini buğday çeşitlerinde memnun olup olmama durumu lojistik regresyon analizi ile test edilmiştir. Anket sorusuna cevap veren 303 bireyin cevaplarından elde edilen analiz sonucu modelde üreticilerin 272'sinin evet cevap verdiğini ve modelin %98,1 doğrulukla tahmin ettiğini ortaya koymaktadır (Tablo 9). Modelde evet diyenler için %1,8'ini ise yanlış tahmin etmiştir. Öte yandan araştırmaya katılan 303 üreticiden 29 üretici ürettiğiniz buğday çeşidinden memnun musunuz? sorusuna hayır cevabı vermiştir. Kurulan model hayır cevabını verenlerin %58'ni doğru tahmin etmiştir.

Tablo 9. Üreticilerin buğday üretiminde bazı faktörler karşısında memnuniyet analizi

		Memnuniyet durumu			
		Evet	%	Hayır	%
Memnuniyet Durumu	Evet	267	98,1	5	1,8
	Hayır	17	58,6	12	41,3

Lojistik regresyon analizi sonucunda üretimi gerçekleştirilen buğday çeşidinden memnun olma durumunu etkileyen bağımsız değişkenlerin bağımlı değişken üzerindeki etkisi anlamlı bulunmuştur (p=0,000) (Tablo 11). İstatistiki olarak üreticilerin tercih edilen buğday çeşidinden memnun olma durumu üzerinde tercih edilen çeşidin hastalığa dayanaklı olması, yöre iklimine uygunluğu ve çeşidin kalitesi üretici memnuniyeti açısından önemli bulunmuştur (p <0,05**).** Üreticilerden tercih ettikleri buğday çeşidi için hastalığa dayanıklı diyenler, çeşit hastalığa dayanaklı değil diyenlere göre yaklaşık olarak 3.5 kat daha fazla memnunlardır. Üreticilere üretimini gerçekleştirdiğiniz çeşit, bölge iklimine ve toprak yapısına uygunmudur sorusu sorulmuş, üretimini yaptıkları buğday çeşidi için bölge iklimi ve toprak yapısına uygun diyenler, uygun değil diyenlere göre 3,5 kat daha fazla memnunlardır. Analiz de bir diğer anlamlı sonuç olan çeşidin kalitesi bakımından değerlendirildiğinde; üreticilerden tercihini yaptığı çeşitin kaliteli olduğunu düşünler, kaliteli olmadığını düşünenlere göre yaklaşık olarak 3,7 kat daha fazla memnundurlar. Buna karşın buğday üretiminde pasla mücadele, zararlılara dayanaklılık, süne mücadelesi, kuraga dayanaklılık, soğuğa dayanaklılık gibi faktörlerin üreticinin tercih ettiği çeşitten memnun olup olmama durumu istatistiksel anlamsız bulunmuştur. Burada üreticinin bu sorunları çözebileceği veya üretimini gerçekleştirdiği çeşitlerin soğuk ve kuraklığa dayanıklılıklarında bir sorun yaşamadığını göstermektedir. Çeşidin sap ve saman verimi ise %10 (p <0,1) güven düzeyinde üretici için önemli bulunmuştur.

Tablo 10. Bağımlı ve bağımsız değişkenlere ait tanımlayıcı özellikler

Değişkenler	(1 Evet) (2 Hayır)	Ortalama	Std. Sapma
Memnuniyet durumu	✓	1,10	0,29
Hastalığa dayanaklılık	✓	1,17	0,38
Yöre iklim ve toprak yapısına uygunluğu	✓	1,10	0,29
Pas mücadelesi yapma durumu	✓	1,42	0,50
Zararlılara dayanıklılık durumu	✓	1,19	0,40
Süne mücadelesi yapma durumu	✓	1,55	0,50
Kuraklığa dayanıklılık	✓	1,26	0,44
Soğuğa dayanıklılık	✓	1,24	0,43
Yabancı otla mücadele	✓	1,11	0,31
Sap-saman memnuniyeti	✓	1,31	0,46
Çeşit kaliteli	✓	1,13	0,33

Tablo 11. Memnuniyet durumunu lojistik regresyon analizi

Değişkenler	B	S.E.	Wald	df	Sig.	Exp(B)
Sabit	-5,82	2,485	0,02	1,00	1,00	0,00
Hastalığa dayanaklılık durumu	1,39	0,67	4,84	1,00	0,03*	3,66
Yöre iklimine ve toprak yapısına uygunluk durumu	1,29	0,74	4,02	1,00	0,04*	3,52
Pasla mücadele yapma durumu	1,62	0,85	3,1	1,00	0,15	3,52
Zararlılara dayanaklılık durumu	0,10	0,64	0,03	1,00	0,78	1,11
Süne mücadelesi yapma durumu	-0,88	0,66	1,78	1,00	0,19	0,47
Kuraklığa dayanaklılık durumu	0,23	0,45	0,15	1,00	0,68	1,28
Soğuğa dayanaklılık durumu	0,77	0,58	2,10	1,00	0,13	2,18
Yabancı ot ilacı kullanım durumu	-0,20	0,82	0,04	1,00	0,92	0,84
Sap-samandan memnun olma durumu	0,91	0,50	2,92	1,00	0,08	2,48
Çeşit kaliteli durumu	1,20	0,60	5,80	1,00	0,02*	3,75
		Chi-square	73,785		Sig.	0.000
		-2 Log likelihood	126,010[a]		Nagelkerke R Square	0,485

önem derecesi; * : 0 .01 ≤ P≤ 0.05; ** : 0.001 ≤ P≤ 0.01

SONUÇ ve ÖNERİLER

Türkiye'de başta kırsal alanlar olmak üzere tarımsal faaliyette bulunan üreticilerin büyük bir çoğunluğunun doğrudan buğday üretimi ile ilişkisi vardır. Sulanamayan alanların fazlalığı ve bu alanlarda buğday dışındaki alternatif ürünlerin buğday karşısında rekabete giremeyişi, buğdayın temel besin ürünlerinin başında gelmesi, üreticilerin geleneksel üretim sürecine devam etme fikri, artan ülke ve dünya nüfusu ve buna karşın buğday talebindeki artış, buğday arzını artırmaya yönelik devlet desteklemeleri ve teşvikleri üreticinin tarım alanlarında buğday üretimini tercih etmesinde fazlasıyla yeterli olmaktadır.

Ancak tüm bunların yanında buğday üreticisi açısından verimliliği artırmak adına ürün çeşit seçimi önemli hale gelmiştir. Türkiye'de buğday üreticileri bölgelerinin iklim yapısı başta olmak üzere toprak özellikleri, arazi yapıları gibi birçok faktöre bağlı kalarak verimli buğday çeşitlerini tercih etmektedirler. Bu çalışmada Adana, Mersin, Kahramanmaraş ve Sivas illerindeki buğday üreticilerinin TAGEM tarafından tescil edilen buğday çeşitlerini tercih etme sebepleri araştırılmıştır. Çalışmada TAGEM tarafından tescil edilen buğday çeşitlerinin tercih edilmesinde üretici memnuniyeti, ortalama dekara verim ve verimliği etkileyen bazı faktörler üzerinden test edilerek etkili olduğu bulunmuştur.

Araştırmada TAGEM tarafından tescil edilen buğday çeşitlerini tercih eden ve ankete katılan buğday üreticilerinin genel yaş ortalaması 49,3 olarak bulunmuştur. Buğday üreticilerinin eğitim seviyelerinin ise ilk, orta ve lise seviyesinde yoğunlaştığı görülmektedir.

Üreticiler; 6 ay üzerinde ikamet ettiği yerler açısından değerlendirildiğinde, buğday üreticilerinin yaklaşık %75'nin köylerde ve büyükşehir yasası ile köy durumundan mahalle statüsüne geçmiş alanlarda yaşadığı görülmektedir.

Buğday üretiminde önemli olan bir diğer demografik özellik ise üreticilerin çiftçilik deneyimidir. Çalışmada çiftçilik deneyimleri yaklaşık ortalama 30 yıl olarak bulunmuştur. Bireylerin, çiftçilik deneyim süreleri yaşları ile kıyaslandığında erken yaşta üreticiliğe başladıkları görülmektedir.

Öte yandan araştırma sorularını cevaplayan buğday üreticilerinin %33'ne yakını bitkisel üretim ile hayvancılık faaliyetini birlikte yapmaktadır. Çalışma sonuçlarına göre Adana ve Mersin illerinde üreticilerin yaklaşık %95'i Adana 99 çeşidini tercih etmektedir. Kahramanmaraş'ta üreticilerin tercihi %60,3'le Eminbey buğday çeşidi yönünde olduğu görülmüştür. Sivas'ta ise en yüksek tercih %51,2 ile Kızıltan 91 çeşidi şeklinde gerçekleşmiştir. Diğer illerde en çok tercih edilen çeşide rakip olmadığı görülürken, Sivas'ta ikinci bir çeşit olan Bayraktar 2000 %36,6 tercihle Kızıltan 91'e rakip olmuştur. Çalışmada dekara ortalama verimi etkileyen faktörler test edilmiştir. Dönem içindeki sulama sayısının, çeşidin soğuğa dayanıklılık durumunun, taban gübresi kullanma durumunun ve üst gübresi kullanma durumunun ortalama verim üzerinde anlamlı ve önemli bir etkisinin olduğu görülmüştür ($P=0.000 <0.05$). Dekara ortalama verimin, sulama sayısının arttırılması ve çeşidin soğuğa dayanaklığının arttırılması, taban gübresi kullanılması ve üst gübresi kullanılması ile önemli miktarda artacağı belirlenmiştir. Bu anlamda verimliliği artırma üzerine yapılan çalışmalarda araştırmacıların bu kriterler üzerinde daha fazla durması önemli olacaktır. Örneğin üretici beyanı esas alındığında bölgede dekara daha verimli çeşitlerin mevcut olduğu ancak bazı yıllarda ortaya çıkan ekstrem soğukların verimi büyük oranda olumsuz etkilediğini ve bundan dolayı üreticinin kendisini güvene alma isteği doğrultusunda daha verimli çeşit yerine soğuğa daha fazla dayanan çeşidi tercih ettiği görülmektedir. Bu anlamda son yıllarda daha verimli çeşitlerin geliştirilmesine rağmen üreticinin bu çeşitleri tercih etmesinde yukarıda belirtilen faktörlerin etkili olduğunu göstermektedir. TAGEM tarafından tescil edilen buğday çeşitlerini kullanan üreticilerin yaklaşık %90'ının çeşitlerden memnun olduğu belirlenmiştir.

Çalışmada üreticilerin buğday çeşidinden memnuniyeti; hastalığa dayanıklı olması, yöre iklimine uygunluğu ve çeşidin kalitesi açısından istatistiki olarak önemli bulunmuştur ($p <0,05$) ve üreticilerin tercih ettikleri buğday çeşidinden memnun olma durumunu önemli derecede etkilemektedir. Bu bağlamda, bölge için yeni çeşit geliştirme aşamasında olan veya geliştirmeyi planlayan araştırmacılar üzerinde çalıştığı çeşidin hastalığa dayanaklı olması durumunu, çeşidin bölge iklim ve toprak yapısına uygunluk durumunu ve çeşit kalitesi özelliğini öncelikli tutmasında fayda vardır. Bölgeye önerilmesi düşünülen çeşitlerin bu özellikler bakımından ön değerlendirilmesinin yapılması, mümkün olduğu durumlarda bölgede ön denemeler yapılarak çeşidin bölge uyumu gözlenmlendikdikten sonra çeşidin üreticiye aktarılması üreticinin çeşidi tercih etmesinde etkili olacağı öngörülmektedir**.** Buna karşın ilginçtir ki pasla mücadele, zararlılara dayanaklılık, süne mücadelesi, kurağa dayanıklılık, soğuğa dayanıklılık gibi faktörlerin üreticinin çeşit tercihinde memnuniyet açısından istatistiği olarak önemsiz olduğunu ortaya koymuştur. Üretici ile gerçekleştirilen diyaloglara dayanılarak üreticinin bu sorunlara karşı toleranslı olduğu, ürünün kaliteli, iklime uygun ve hastalığa dayanaklı olmasıyla bu problemleri tolere edebileceğini göstermektedir.

Sonuç olarak Adana, Mersin Kahramanmaraş ve Sivas illerinde TAGEM tarafından tescil edilen buğday çeşitlerini kullanan üreticilerin bu çeşitlerden memnun olduğu belirlenmiştir. Ancak çeşidin kalitesi, hastalığa dayanıklılık ve yöre iklimine uygun çeşitlerin geliştirilmesi gerekliliği vardır. Öte yandan tercih edilen ve memnun olunan buğday çeşitlerinin tescil tarihlerine bakıldığında Adana 99 çeşidi 1999 yılında, Kızıltan 91 çeşidi 1991

yılında ve Eminbey çeşidi ise 2009 yılında tescil edilmiştir. Tarihler anlamında uzun süreler öncesinde tescil edilen buğday çeşitleriyle rekabet edebilecek, tercih önceliği sağlamayan çeşitlerin geliştirilememesi önemli bir eksiklik olarak görülmektedir. Bu anlamda Ar-ge çalışmalarına önem verilmelidir. Ayrıca ürün kalitesine etkisi yüksek olan sulama sayıları ile ilgili alt yapısı uygun bölgelerde sulama alt yapıları oluşturularak, sulama faaliyetlerinin daha etkin geliştirilmesi için eğitimler düzenlenebilir.

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Original Article

The Impact of Agricultural Financialization on Agricultural Output: The Case of Türkiye

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ABSTRACT

The primary purpose of the present study is to examine the impact of agricultural financialization on agricultural output in Türkiye. The reference period of the research consisted of 1994-2023 period. Variables were created with dataset of the Banks Association of Türkiye and the World Bank. In the empirical model, agriculture, forestry and fishing value added (% of GDP) (AGRVD) was selected as the dependent variable to represent agricultural output and agricultural specialized loans provided by banks (% of GDP) (AGRCD) was determined as the independent variable to represent agricultural financialization. Additionally, exports of goods and services (% of GDP) (XGS) was included in the model as a control variable. Standard diagnostic tests were used to determine the properties of the data. The Autoregressive Distributed Lag Bound Test (ARDL) and Error Correction Model (ECM) were used to estimate long and short run relationship respectively. The study found that agricultural financialization has a significant impact on agricultural output in Türkiye. It was found that series in the empirical model were cointegrated. Furthermore, Fully Modified Ordinary Least Squares (FMOLS) test results, conducted to verify the accuracy of the findings, indicated that a 1% increase in AGRCRD led to a 1.73% increase in AGRVD, while a similar increase in XGS resulted in a 0.36% decrease in AGRVD. In the direction of the evidence, this study recommends continuing policies that facilitate access to credit and other financial instruments for the agricultural sector to enhance agricultural output. The study recommends continuing policies that facilitate access to credit and other financial instruments for the agricultural sector to enhance agricultural output.

Key words: Agricultural Financialization, Agricultural Output, Türkiye.

Tarımsal Finansallaşmanın Tarımsal Çıktı Üzerindeki Etkisi: Türkiye Örneği

ÖZ

Çalışmanın temel amacı, Türkiye'de tarımsal finansallaşmanın tarımsal çıktı üzerindeki etkisini incelemektir. Veri seti, 1994-2023 yılları arasındaki 30 yıllık dönemi kapsamaktadır. Değişkenler, Türkiye Bankalar Birliği ve Dünya Bankası veri setleri kullanılarak oluşturulmuştur. Bağımlı değişken olarak, tarımsal çıktıyı temsilen, tarımsal katma değerin GSYİH'ye oranı (AGRVD), bağımsız değişken olarak ise, tarımsal finansallaşmayı temsilen, bankalarca sağlanan tarımsal ihtisas kredilerin GSYİH'ye oranı (AGRCRD) seçilmiştir. Ayrıca mal ve hizmet ihracatının GSYİH'ye oranı (XGS) modele kontrol değişken olarak eklenmiştir. Verilerin özelliklerini belirlemek için standart tanılayıcı testler kullanılmıştır. Uzun dönem ve kısa dönem ilişkileri tahmin etmek amacıyla Gecikmesi Dağıtılmış Otoregresif Sınır Testi (ARDL) ve Hata Düzeltme Modeli'nden (ECM) yararlanılmıştır. Çalışmada, Türkiye'de tarımsal finansallaşmanın tarımsal çıktı üzerinde anlamlı bir etkisi olduğu sonucuna varılmıştır. Kullanılan modelde yer alan serilerin kısa ve uzun dönemde birlikte hareket ettikleri görülmüştür. Bulguların doğruluğunu teyit etmek amacıyla yapılan Tamamen Değiştirilmiş En Küçük Kareler (FMOLS) testi, AGRCRD'deki %1'lik bir artışın AGRVD'yi %1,73 oranında artırdığını, XGS'deki benzer bir artışın ise AGRVD'yi %0,36 oranında azalttığını göstermektedir. Elde edilen kanıtlar doğrultusunda, bu çalışma tarım sektöründe üretimi artırmak amacıyla krediye ve diğer finansal araçlara erişimi kolaylaştıran politikaların devam ettirilmesini önermektedir.

Anahtar kelimeler: Tarımsal Finansallaşma, Tarımsal Çıktı, Türkiye.

INTRODUCTION

Financialization refers to the liberalization, deepening, and broadening of the financial structure, or the increasing role of financial markets, actors, and instruments in national and international coordination (Epstein, 2005; Sawyer, 2013). Agricultural financialization, on the other hand, refers to the influence of financial market actors and instruments on the agricultural production process (Clapp et al., 2015). While financialization has long been studied as a significant dynamic in market economies, the relationship between agriculture and finance—although not a new phenomenon—began to be seriously examined only after the 2008 global food crisis. Previous studies have linked agricultural financialization to issues such as food security, price volatility, land acquisition by non-agricultural sectors, and agricultural output. This study, however, focuses specifically on the impact of agricultural financialization on agricultural output in the case of Türkiye.

The relationship between agriculture and finance is not a new phenomenon. For centuries, both informal and formal finance have played an important roles in the agricultural sector. The informal financial consists of individuals such as kith and kin, merchants, moneylenders, and brokers. The financing obtained from this sector is usually short-term -lasting only until the harvest- and tends to be costly. In contrast, the formal financial includes legal institutions and organizations such as banks, futures exchanges, and insurance companies. Among these, banks are the primary actors that continuously reproduce and shape the relationships between farmers and financial institutions. Banks are at the center of the financialization process in the agricultural sector by providing loans for the procurement of inputs such as land, seeds, fertilizers, plant protection products, and animal feed. As profit-oriented businesses, banks generally prefer to lend to enterprises and farmers who can demonstrate the ability to generate profit (Grivins et al., 2021). The second actor that plays an active role in the financialization of agriculture is futures exchanges. In these exchanges, purchase and sale contracts for agricultural products are arranged, and these contracts are traded. These contracts are traded on futures exchanges under the category of “commodity futures contracts”. Until the twentieth century, futures trading was a function of the productive dimension of agriculture (Bonanno, 2016), whereas today, futures and options contracts contribute to the financialization of the agricultural sector by creating price speculation (Manogna & Kulkarni, 2024). Although the 2008 food crisis had multiple causes, many researchers point to the dramatic increase in speculative financial activities in agricultural futures markets as a key driver (Stephens, 2024). Agricultural insurance is another actor in the financialization process. It which was first implemented in Western Europe in the seventeenth century aims to reduce the financial risk and uncertainty faced by the agricultural sector by providing protection against crop losses due to natural disasters such as drought, floods, hailstorms, pest attacks, disease outbreaks and other events that can damage crops or livestock. Agricultural insurance facilitates access to credit for farmers and agribusinesses, since lenders generally favor those with comprehensive coverage. Additionally, it facilitates the sustainability of the agricultural credit system by reducing financial stress (Lee et al., 2023). It would be appropriate to begin the formal financialization of agriculture in Türkiye with the Ottoman Empire's adoption of western models in trade and finance. In the 19th century, due to the absence of a local, organized, and stable agricultural credit system in the Ottoman Empire, foreign banks assumed this task. State Cases were created with the aim of offering low-interest loans to the agricultural sector in order to stimulate agricultural production. By 1888, these funds transformed into a modern financial institution- Ziraat Bank- which was officially founded to take over their duties (Dereci, 2023). Thus, the first domestic and official actor in the financialization of Turkish agriculture emerged. The next significant development to facilitate access to agricultural credit was the enactment of the Agricultural Sales Cooperatives and Unions Law and the Agricultural Credit Cooperatives Law in 1935. The fact that the articles of these cooperatives were prepared by Ziraat Bank demonstrates that the bank also provided financing for these associations (Orak, 2022).

Approximately a decade after the enactment of this law, with the end of World War II, foreign actors began to play a role in the financialization of Turkish agriculture. Under the Marshall Plan, Türkiye received a total of $352.3 million in aid, including $194.9 million in grants and $140 million in loans. This situation made Türkiye dependent on the United States for the procurement of spare parts for agricultural tools, machinery, and equipment, effectively causing a portion of the aid funds to flow back to the U.S. (Karaman & Yavuz, 2016). With the start of the planned development period in the Turkish economy, agricultural loans were incorporated into the development plans. In the First and Second Five-Year Plans, it was emphasized that loans should be provided only to farmers of a certain scale through cooperatives (SBB, 2025; SBB, 2025a). This practice made the Ziraat Bank, the Ministry of Agriculture and the Agricultural Credit Cooperatives the three major actors in the

financialization of agriculture in the first ten years of the planned period. In the Third and Fourth Five-Year Plans, it was recommended that loans be provided to small-scale farmers in kind through cooperatives (SBB, 2025b; SBB, 2025c). In the 1980s, the Turkish economy underwent a major transformation, and the agricultural sector was also impacted by this change.The agricultural support system was terminated with the Agricultural Reform Implementation Project (ARIP) supported by the World Bank (WB) and the Agreement on Agriculture (AoA) suportd by the World Trade Organization (WTO) (Yükseler, 1999). In 2000, Direct Income Support (DIS) was introduced as a replacement for the previous support system. The first-year expenses of DIS were covered by credits from the World Bank and allocations from Türkiye's Central Government Budget (Ay & Yapar, 2005).

After the economic crisis of the 2000s, financial investors-faced with increased risks in the industrial and service sectors-turned to the agriculture in an effort to make their portfolios safer and their returns more secure. Turkish agriculture was an untapped area for private banks. High commission incomes, wide interest rate spreads and extensive lending opportunities had whetted their appetite. In 2004, the influence of foreign capital in the banking sector increased significantly. As a result, a new era began in banking, and privately-owned banks started working with the agricultural sector (Yıldırım, 2008). In 2002, only three privately owned banks provided agricultural loans in Türkiye; by 2023, this number had increased to fifteen. Among them, Denizbank has taken the leading position among private banks in agricultural banking, with a 37% market share (Denizbank, 2023). By the year 2020, the implementation of low-interest (subsidized) investment and operating loans for agricultural production once again brought public banks to the forefront in providing loans to the agricultural sector. The low-interest investment and business loan policy for agricultural production launched by the government in 2020 has brought public banks to the forefront again in loans given to the agricultural sector.

In Türkiye, the futures and options exchange is the second most significant actor in the financialization of Turkish agriculture. The Turkish Mercantile Exchange (TMEX), which began operations in 2019, plays a key role in this process.TMEX was established to facilitate the trading of electronic product notes created by licensed warehouse operators in accordance with the relevant legislation, as well as futures contracts based on these notes. Electronic Warehouse Receipts(EWR), which are digital documents representing products stored in licensed warehouses, can only be traded on TMEX. In the TMEX EWR Market, a variety of agricultural products are traded, including barley, wheat, and corn, as well as pistachios, legumes, hazelnuts, dried apricots, cotton, and olives. From 2019 to 2023, the volume of trade increased more than fivefold, rising from 2.4 million kg to 12.3 million kg. During the same period, the traded value increased from 3 million TL to 82 million TL, the number of registered investors grew from 49.4 thousand to 216 thousand, and the number of active traders rose from 26.6 thousand to 95.2 thousand. Furthermore, the issuance of asset-backed securities and lease certificates based on the bread wheat price index published by TMEX has contributed to the financialization of the agricultural sector (TMEX, 2023; TMEX, 2024). Also, some companies operating in production or marketing within the agricultural sector in Türkiye are traded on BIST. BIST Food Beverage Index (XGIDA) was created in 1996 to follow the general trend of this sector, measure its performance and provide investors with information about the sector. As of March 4, 2025, the index has 46 components and a total value of 580.9 billion TL, with 1,743,803 investors (BIST, 2025).

Another important actor in the financialization of Turkish agriculture is agricultural insurance. Although the first agricultural insurance was provided by Ziraat Bank in 1937, a comprehensive insurance mechanism to cover the risks threatening the agricultural sector was not implemented until 2005. That year, the Agricultural Insurance Pool (TARSİM) was established through a collaboration between the public and private sectors. The state contributes between 50% and 60% of the insurance premium. In 2005, only 9 out of 62 insurance companies in Turkey were actively issuing agricultural policies; this number increased to 26 by 2023 with the establishment of TARSİM (TARSİM, 2024). The number of issued policies rose from 1.598 million in 2017 to 3.087 million in 2023. Between 2015 and 2023, the ratio of paid loss compensation to total premiums reached its lowest level in 2022 at 0.38 and its highest in 2015 at 0.75. When state support is excluded from total premiums, this ratio approximately doubles. In both 2019 and 2021, the paid loss compensation exceeded the collected insured premiums (TARSİM, 2020; TARSİM, 2024).

The financialization of agriculture is a phenomenon that has been studied from various perspectives in the literature. One area of focus is its impact on agricultural output. Although few studies have addressed this issue, their findings vary. These differences in results can be attributed to factors such as the size of the economy, openness to international markets, volume of financial transactions, trust in the financial system, and households' tendency to save. For example, while Sial et al. (2011) for Pakistan, Ogbuabor & Nwosu (2017) for Nigeria, Peng et al. (2021) for China, Hartarska et al. (2015) for the United States, and Shuaibu & Nchake (2020) for West and Southern Africa concluded that agricultural financialization has a positive effect on agricultural output, Anh et al. (2020) for Vietnam, Nawaz (2011) for Pakistan, Chisasa & Makine (2015) for South Africa, Farooq et al. (2024) for India, Pakistan, Bangladesh, Sri Lanka, and Nepal, and Shuaibu & Nchake (2020) for

Central and East Africa found that agricultural financialization has a negative affect on agricultural output. On the other hand, Kochar (1997) for India, Reyes et al. (2012) for Chile, Nakazi & Sunday (2020) for Uganda and Meressa (2017) for Ethiopia argued that agricultural financialization has no effect on agricultural output. Moreover, Sosoo et al. (2021) claim that commodity futures negatively impact food security in low, middle, and high-income countries. Similarly, Gilbert (2010) states that futures in agriculture can lead to market distortions and hinder farmers' access to financial instruments, thereby exacerbating the impact of supply shocks, especially in developing countries. Besides this Irwin & Sanders (2011) argued that the 2008 food crisis was not driven by excessive price speculation, but rather by fundamental supply and demand factors. Vercammen & Doroudian (2014) and Brunetti et al. (2016) agree with Irwin & Sanders (2011). , They argue that speculation did not destabilize the market; instead, speculative trading reduced market volatility and improved overall market quality.

There is not a very extensive body of literature on the relationship between agricultural financialization and agricultural output. Among the existing studies, there is no research that specifically examines the relationship between the financialization of Turkish agriculture and agricultural output. In this regard, the present study aims to fill a gap in the literature and contribute to a better understanding of the subject. The aim of this study is to investigate the impact of agricultural financialization on agricultural output in the Turkish economy. The structure of the study follows a standard research format. The first section provides an introduction. The second section explains the econometric methodology used for the study and gives a description of the data used. The third section presents the results and discussion. In the final section, a general evaluation of the results is made, and policy recommendations are provided.

MATERIALS AND METHODS

Undoubtedly, as in all economies, agriculture is an indispensable sector in the Turkish economy. The agricultural sector accounts for approximately 6% of Türkiye's national income, 4% of total foreign trade, and employs about 15% of the total workforce. To support the development of the agricultural sector, various instruments have been utilized, including banks, agricultural credit and sales cooperatives, agricultural insurance, and commodity exchanges. This process has also contributed to the financialization of Turkish agriculture. However, the relationship between the financialization of agriculture and agricultural output remains unclear. The main purpose of the study is to investigate this relationship.

In this section of the study, the effect of the financialization of agriculture in the Turkish economy on agricultural output is analyzed using econometric methods. The study is based on time series data. In the reference model utilized in the study, agriculture, forestry, and fishing value added (% of GDP) (AGRVD) was selected as the dependent variable to represent agricultural output and agricultural specialized loans provided by banks (% of GDP) (AGRCD) was determined as the independent variable to represent agricultural financialization. Additionally, exports of goods and services (% of GDP) (XGS) was included in the model as a control variable. Since all the variables used are in ratio form and the series do not exhibit homogeneity issues, the original forms of the series have been used in the study. The study covers the period from 1994 to 2023, and the abbreviations, explanations of the variables included in the model, and the final econometric form of the model are presented in Table 1.

Table 1. Definition of variables

Variables	Definition	Source
AGRVD	Agriculture, Forestry, and Fishing Value Added (% of GDP)	World Bank
AGRCRD	Specialized Agricultural Loans (%of GDP)	The Banks Association of Türkiye
XGS	Exports of Goods and Services (% of GDP)	World Bank

In line with the objective of the study, several tests have been utilized as the research methodology. These include unit root tests, diagnostic tests, and cointegration tests. In the unit root analysis, the Augmented Dickey-Fuller (ADF) test (1981) and the Phillips-Perron (PP) test (1988) were employed, as they are among the most commonly used unit root tests in the economics scientific literature. The main purpose of using unit root tests is to determine whether the series are stationary. When nonstationary time series are used in a regression model, the results may spuriously indicate a significant relationship when there is none. Therefore, the first difference of the variables should be used to eliminate regression errors. Three different models are used in the Dickey-Fuller (1981) Unit Root Test (Akcan et al., 2022):

$$\Delta Y_t = \lambda Y_{t-1} + u_t \, .$$

$\Delta Y_t = a_0 + \lambda Y_{t-1} + u_t$.
$\Delta Y_t = a_0 + a_1 t + \lambda Y_{t-1} + u_t$.

In the ADF Unit Root Test, it is assumed that the error terms are independent and have a constant variance. For this reason, in order for the test to give definite results, it is necessary to ensure that there is no correlation between the error terms and that the variance is constant. Based on this situation, in 1988, P. Phillips and P. Perron (PP) developed an alternative different unit root test that is sensitive to the correlation and variable variance in the error terms. The following equation is used in this test (Akcan et al., 2022):

$$T_{\ddot{o}} = t\delta\left(\frac{y_0}{f_0}\right)^{1/2} - \frac{T(f_0 - y_0)[se(\hat{s})]}{2\sqrt{f}s}$$

To determine whether the variables are cointegrated in the long run, the Autoregressive Distributed Lag (ARDL) test proposed by Pesaran et al. (2001) was applied because it makes possible to identify the long-run cointegration relationship between the variables, even when the variables are stationary at different levels. In the ARDL test, the equations have lower and upper bound of critical values (Pesaran et al., 2001). Information on the upper bound is obtained by using the critical values of Narayan (2005). Three different results may arise depending on the calculated F-statistic values. If the F- statistic is larger than the upper bound of the critical values, it is accepted that the coefficients are different from each other and from zero and therefore there is a cointegration. If the F-statistic is lesser than the lower bound of the critical values, it is accepted that the coefficients are equals each other and zero. That means there is a no cointegration relation. If the F-statistic falls between the upper and lower bounds, a definitive judgment on the existence of the cointegration relationship cannot be made. The ECM test can be applied to evaluate the speed parameter of the short-run association between the variables after cointegration test appears long-run association among the variables. (Emam, 2020; Hüsnüoğlu ve Durkaya, 2023).

The reference empirical model of this study, when redefined in the methodological form of the ARDL Bounds Test, can be expressed as follows:

$$\Delta AGRVD_t = \beta_0 + \sum_{i=1}^{m} \beta_{1i}\, \Delta AGRVD_{t-1} + \sum_{i=0}^{n} \beta_{2i}\, \Delta AGRCRD_{t-i} + \sum_{i=0}^{p} \beta_{3i}\, \Delta XGS_{t-i} + u_t.$$

RESULTS AND DISCUSSION

Firstly, descriptive statistics of the series for the econometric equation used were given. Following descriptive statistics, unit root test results were presented. After determining whether the series were stationary, diagnostic tests were applied, and then the cointegration test results were shown.

Table 2. Descriptive statistics of the variables

Variables	Number of observations	Mean	Median	Maximum	Minimum	Std. Dev.
AGRVD	30	8.930124	8.083435	16.85456	5.533753	3.139465
AGRCRD	30	1.894167	1.725500	5.217000	0.653000	1.099878
XGS	30	24.98748	23.59552	38.58420	18.81091	4.808430

Table 3. Unit root analysis

Variables	ADF	PP
AGRVD (Level)	-2.06/-1.70/-2.48**	-3.62**/-1.19/-3.41***
AGRCRD (Level)	-2.51/-1.98/-1.27	-1.99/-1.88/-1.19
XGS (Level)	0.44/-2.83/1.65	-1.53/-2.83/1.36
AGRVD (1st difference)	-4.62***/-4.14**/-4.22***	-4.61***/-5.84***/-4.22***
AGRCRD (1st difference)	-6.24***/-6.37***/-6.29***	-6.40***/-6.47***/-6.41***
XGS (1st difference)	-6.72***/-6.95***/-6.29***	-7.03***/-9.19***/-5.49***

Not: Note: *** and ** indicate that the series are significant at the 1% and 5% critical levels, respectively. The values represent three different econometric equations (constant, constant and trend, no constant and no trend).

According to the unit root test results shown in Table 3 all series are stationary after performing first difference 1(1). However, AGRCRD becomes stationary at different levels in the 3rd equation of the ADF and in the 1st and

3rd equations of the PP test. Since the series contains both constant and trend information and shows strong stationarity in the 1st difference, the analysis was continued by assuming that this series is I(1). The analysis was continued because the series contained both constant and trend information and showed strong stationarity in the 1st difference.Table 4 presents the diagnostic test results for the model.

Table 4. Diagnostic test result

Test	Hypothesis	Statistics	Result
Breusch-Godfrey LM	There is no autocorrelation problem.	0.4535	Accepted.
Jarque-Bera	The model is normaly distributed.	0.9115	Accepted.
Breusch-Pegan-Godfrey	There is no heteroscedasticity problem.	0.8113	Accepted.
Correlation Test	There is no multicollinearity problem between AGRCRD and XGS.	-0.0464 < 0.90	Accepted.

According to the diagnostic test results, the reference model confirms the basic assumptions that a reliable model should contain. In other words, the model does not have autocorrelation, heteroscedasticity and non-normaly distribution problems. Additionally, the highest correlation between the series is found to be -0.0464 (AGRCRD and XGS). In this case, the reference model appears to be suitable for cointegration test. Table 5 presents the results of the ARDL cointegration test.

Table 5. ARDL cointegration and error correction model test results

Test statistics	Value		Critical level	I(0)	I(1)
F-statistic	4.764726	k = 3	%10	2.676	3.586
			%5	3.272	4.306
			%1	4.614	5.966
Variable	Coef.		Std. Error	T-statistic	Prob.
CointEq(-1)*	-0.261278		0.054921	-4.757357	0.0002

The obtained F-statistic value is found to be above the critical values calculated by Narayan (2005) at the 1% and 5% significance levels. Based on this, the hypothesis that the series in the model are not cointerated in the long run was rejected.

The structural stability of the equations is observed through the CUSUM and CUSUMQ tests. CUSUM and CUSUMQ detect sudden changes from the constancy of the regression coefficients. The results in Figures 1 shows that the test statistics are within 5% confidence interval band. This suggests that estimated model is stable over time.

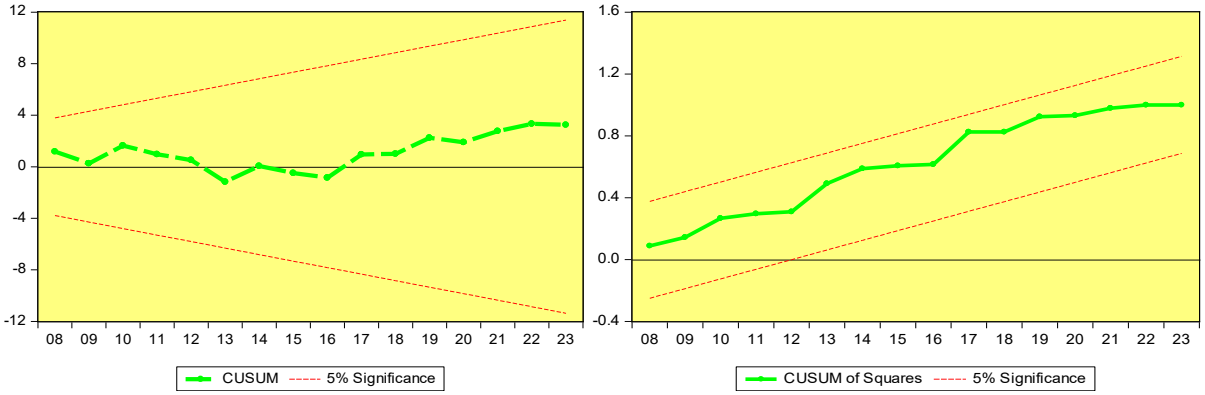

Figure 1.CUSUM and CUSUMQ results

In addition to the long-term analysis, the ECM coefficient was found to be statistically significant and calculated as -0.261278. This means that the mechanism of error correction is running well, and the system can return to the long-term steady trajectory.In this case, it is understood that the shock effect in agricultural credits dissipates in the 4th period (1/0.2612 = 3.8). In light of the identified results, the Fully-Modified OLS (FMOLS) test results are presented in Table 6.

Table 6. Fully-Modified OLS test results

Variables	Coefficient	Std. Error	t-statistic	Prob.
AGRCRD	1.737601	0.452904	3.836573	0.0007***
XGS	-0.369597	0.102346	-3.611265	0.0013
C	14.86164	2.760533	5.383614	0.0000
Depented variable=AGRVD - R^2=0.619845				

According to the FMOLS test results, both explanatory variables in the model were found to be statistically significant. While AGRCRD has positive effect on AGRVD, XGS has an inverse effect on it. It was found that the change in the explanatory variables of the model explains about 62% of the change in agricultural output. Indeed, the coefficient of AGRCRD shows that an increase of 1% will raise AGRVD 1.73% and AGRVD is a positive function of AGRCRD and exhibits an elastic characteristic. Conversely, a similar increase in XGS reduces AGRVD by 0.36% and this coefficient indicates that the elasticity of AGRVD with respect to XGS is relatively low.

CONCLUSION

The relationship between finance and agriculture, which began with informal financial practices, has significantly evolved with the emergence of formal finance. Today, institutions such as banks, exchanges, and insurance companies play a vital role in the financialization of agriculture. Banks provide financial resources both for agricultural production and modernization, as well as for the daily needs of the producer sector. 6öExchanges, on the other hand, facilitate the trading of forward agricultural commodity contracts and contribute to price speculation. Agricultural insurance supports the sustainability of the agricultural credit system by reducing the financial risks and uncertainties faced by the sector, thereby contributing to the financialization of agriculture.

It is also possible to see the impact of these actors in the financialization process of Turkish agriculture. Formal financing began in 1867 with the establishment of the State Cases, and its institutionalization occurred in 1888 with the establishment of the Ziraat Bank. The cases were transformed into bank branches. Ziraat Bank also undertook the financing of the Agricultural Credit Cooperatives that were later put into operation. The liberalization process of the Turkish economy, which started with the January 24 decisions, affected the agricultural sector and the decisions of international organizations began to be effective in agricultural production. During this period, state support was reduced to a minimum and farmers were forced to take on more debt. This situation benefited privately-owned banks, and by the early 2000s, the banks began competing with each other to lend to the agricultural sector. However, in 2020, the application of low-interest investment and business loans for agricultural production brought public banks to the forefront again in loans given to the agricultural sector. In 2020, the government's subsidized low-interest agricultural credit policy brought public banks back to the forefront in loans given to the agricultural sector. Another important step in the financialization of Turkish agriculture was the launch of TMEX in 2019. EWRs are traded on TMEX, whereas securities issued by some companies operating in the agricultural production and marketing sectors are traded on BIST.

This study empirically examines the impact of agricultural financialization on agricultural output using annual data from 1994 to 2023 for Türkiye. Three key findings emerge from the analysis. First, agricultural financialization has a significant impact on agricultural output in Türkiye. Second, the time series used in the empirical model are cointegrated, indicating the presence of a stable long-term relationship among the variables. Third, the agricultural financialization elasticity of agricultural output is quite high. This implies that a one percent increase in financialization leads to a growth in agricultural output of more than one percent. Overall, the empirical findings highlight that the financialization of agriculture is a highly significant factor for the sector in Türkiye.

In light of the findings of the study, it is recommended to facilitate access to financial instruments in order to enhance agricultural output and support the development of the agricultural sector. Given the growing concerns over future climate and food crises, increasing both the quantity and quality of agricultural production becomes even more important. In this context, it is recommended that the public sector develop transparent and supportive policies to improve access to financial instruments for agricultural producers and entrepreneurs. Thus, the increased supply will meet the rising domestic demand and reduce dependency on food imports. As a result, the foreign exchange pressure on the Turkish economy will also decrease relatively.

Very small number variables are considered for this research study in order to determine their impact on the agricultural output. These variables are agricultural credit and exports of goods and services. However, there might be many other such variables that have an impact on agricultural output. Thus, for future studies many other important variables such as agricultural insurance, human capital, climate change , agricultural technologies etc. should also be taken into count. This will help in determining the impact of different input variables as well which will help in improving the required outputs.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

Mustafa BAYLAN **:**Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; writing— original draft; writing—review and editing.

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Original Article

The Asymmetric Effects of Agricultural Policy Support on Agricultural Employment in Türkiye: A NARDL Approach

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ABSTRACT

The agricultural sector is recognized as one of the primary economic pillars of Türkiye, contributing significantly to employment, GDP, and export revenues. However, the proportion of the workforce employed in agriculture has been diminishing in conjunction with the growth of the industrial and service sectors. Despite this long-term decline, annual fluctuations in the absolute value of agricultural employment suggest that the sector functions as a stabilizing factor, mitigating the impact of general labor market fluctuations and exhibiting high sensitivity to short-term changes in profitability and support policies. To support this sector, the government implements various policy instruments, including direct payments, input subsidies, and investment incentives. The extant literature suggests that the effects of these subsidies on employment exhibit a complex and paradoxical pattern. The promotion of capital-intensive technologies, the absence of direct employment effects associated with decoupled payments, and the consolidation of large-scale farms are the main mechanisms through which these interactions occur. It has been emphasized that reducing support could lead to more abrupt and disproportionate declines in employment, particularly by driving less efficient farms out of the sector. This reflects a downward asymmetry. In this context, the study analyzed the short- and long-term asymmetric effects of agricultural policy support, as measured by the OECD Producer Support Estimate (PSE) index, on agricultural employment levels in Türkiye. The dataset used for this study consists of annual time series data on agricultural employment, PSE, agricultural credit volume, agricultural product exports and imports, and the share of agriculture in gross domestic product (GDP) from 1986 to 2023. This data was obtained from the TurkStat, SBB, TBB, and OECD databases. The asymmetric relationships are tested using the NARDL cointegration methodology, which is a non-linear lag distributed autoregressive approach. According to the findings, positive shocks in PSE and agricultural credits significantly and positively affect employment in the long run, while positive shocks in agricultural exports negatively affect employment. Conversely, negative shocks to the share of agriculture in GDP increase employment, confirming the sector's "employment buffer" function. Long-run asymmetry is found in PSE and agricultural credits. In the short run, negative shocks to agricultural exports negatively impact employment, while positive shocks to agricultural credit have a negative lagged effect on employment. However, positive shocks to the share of agriculture in GDP increase employment in the short run. Short run asymmetry is observed for export and GDP share variables, but no significant asymmetry is found for PSE. Accordingly, the study suggests that policymakers adopt a multidimensional approach to agricultural subsidies that considers not only the amount, but also the design, orientation, and implementation context. The development of mechanisms that safeguard rural employment and promote alternative employment opportunities is of critical importance. It is recommended that flexible support and credit instruments be designed to target vulnerable groups in the face of short-term negative shocks, with priority given to labor-intensive subsectors and rural diversification initiatives. Moreover, policies aimed at facilitating transitions to non-agricultural employment—such as vocational training programs and support for local entrepreneurship—should be strengthened.

Key words: Producer support estimate (PSE), asymmetric effects, NARDL, cointegration

Türkiye'de Tarım Politikası Desteklerinin Tarımsal İstihdam Üzerindeki Asimetrik Etkilerinin Analizi: NARDL Yaklaşımı

ÖZ

Tarım sektörü, Türkiye ekonomisinin temel unsurlarından biri olarak, istihdam, GSYH katkısı ve ihracat gelirleri açısından kritik bir rol oynamaktadır. Ancak, sanayileşme ve hizmet sektörlerinin genişlemesiyle birlikte tarımın toplam istihdam içindeki payı düşüş eğilimi göstermektedir. Bu uzun vadeli düşüşe rağmen, tarımsal istihdamın mutlak değerlerinde gözlenen yıllık dalgalanmalar, sektörün genel işgücü piyasası şoklarını hafifletici bir tampon işlevi gördüğünü ve kısa vadeli karlılık değişimleri ile destek politikalarına karşı oldukça duyarlı olduğunu göstermektedir. Bu sektörü desteklemek amacıyla, devlet tarafında doğrudan ödemeler, girdi sübvansiyonları ve yatırım teşvikleri gibi çeşitli politika araçları uygulamaktadır. Literatürde, bu desteklerin istihdam üzerindeki etkilerinin karmaşık ve paradoksal bir örüntü sergilediği belirtilmektedir. Özellikle sermaye-yoğun teknolojilerin teşviki, ayrıştırılmış ödemelerin doğrudan istihdama etkisi olmaması ve büyük ölçekli çiftliklerin konsolidasyonu, bu etkileşimlerin temel mekanizmalarını oluşturmaktadır. Desteklerin azaltılmasının ise, özellikle verimsiz işletmelerin faaliyet dışına itilmesiyle istihdamda daha ani ve orantısız düşüşlere neden olabileceği, aşağı yönlü bir asimetri gözlendiği vurgulanmaktadır. Bu bağlamda çalışma Türkiye'de OECD Üretici Destek Tahmini (PSE) endeksiyle ölçümlenen tarımsal politika desteklerinin, tarımsal istihdam seviyesi üzerindeki kısa ve uzun dönemli asimetrik etkileri analiz etmek amacıyla yapılmıştır. Çalışmada kullanılan veri seti 1986-2023 dönemine ilişkin tarımsal istihdam, PSE, tarımsal kredi hacmi, tarımsal ürün ihracatı, tarımsal ürün ithalatı ve tarım sektörünün gayri safi yurt içi hasıla (GSYH) içindeki payına ait yıllık zaman serileri oluşturmakta olup, TÜİK, SBB, TBB ve OECD veri tabanlarında elde edilmiştir. Çalışmada asimetrik ilişkilerin ampirik olarak test edilmesinde Doğrusal Olmayan Gecikmesi Dağıtılmış Otoregresif (NARDL) eşbütünleşme metodolojisi kullanılmıştır. Bulgulara göre uzun dönemde, PSE ve tarımsal kredilerdeki pozitif şoklar istihdamı anlamlı ve pozitif yönde etkilerken, tarımsal ihracattaki pozitif şoklar istihdamı azaltmaktadır. Tarımın GSYH içindeki payındaki negatif şoklar ise istihdamı artırarak sektörün "istihdam tamponu" işlevini teyit etmektedir. PSE ve tarımsal kredilerde uzun dönemli asimetri olduğu tespit edilmiştir. Kısa dönemde, tarımsal ihracattaki negatif şoklar istihdam üzerinde negatif etki yaratırken, tarımsal kredilerdeki pozitif şokların gecikmeli etkisi istihdamı azaltmaktadır. Tarımın GSYH içindeki payındaki pozitif şoklar ise kısa dönemde istihdamı artırıcı bir rol oynamaktadır. İhracat ve GSYH payı değişkenlerinde kısa dönemli asimetri gözlenirken, PSE için kısa dönemde anlamlı bir asimetri bulunmamıştır. Bu doğrultuda çalışma, politika yapıcılara, tarımsal desteklerin sadece miktarını değil, aynı zamanda tasarımını, yönelimini ve uygulama bağlamını da dikkate alan çok boyutlu bir yaklaşım benimsemeleri önerilmektedir. Özellikle, kırsal bölgelerde istihdamı koruyucu ve alternatif istihdam olanaklarını destekleyici mekanizmaların geliştirilmesi büyük önem taşımaktadır. Esnek destek ve kredi araçlarının, kısa vadeli negatif şoklara karşı kırılgan grupları hedef alacak şekilde tasarlanması; emek-yoğun alt sektörlere ve kırsal çeşitlendirme faaliyetlerine öncelik verilmesi; tarım dışı istihdam geçişlerini kolaylaştıracak mesleki eğitim ve yerel girişimcilik desteklerinin artırılması önerilmektedir.

Anahtar kelimeler: Üretici destek tahmini (PSE), asimetrik etkiler, NARDL, eşbütünleşme.

INTRODUCTION

The agricultural sector is a key pillar of the Turkish economy. It has historically played a critical role in the country's employment structure and made significant contributions to the gross domestic product (GDP). Additionally, it has provided substantial support for rural development through export revenues (FAO, 2025). The sector's strategic importance stems from ensuring national food security, protecting food sovereignty, supplying the industrial sector with raw materials, and providing livelihoods for a significant portion of the rural population (Bayramoğlu & Gündoğmuş, 2008; Terİn et al., 2013; Yavuz, 2024). As of 2023, the agricultural sector employed about 14.84% of the total workforce and accounted for 6.62% of the GDP (TurkStat, 2025). Furthermore, Türkiye is among the leading countries in global agricultural product production, including hazelnuts, apricots, figs, and cherries. This endows the country with a substantial competitive advantage in international markets (FAO, 2025).

In addition to the economic size of the agricultural sector and its competitive position in the global market, the historical development of employment in the sector and its position within the changing economic structure are also important. The structural transformations undergone by the Turkish economy have had a significant impact on the sector's employment capacity, and the share of agriculture in total employment has undergone a transformation over time, particularly with the expansion of the industrialization and services sectors.

During the mid-20th century, the agricultural sector, which constituted approximately three-quarters of the total workforce, underwent a decline in its share of total employment as part of a broader economic transformation (Erhalim, 2011). For instance, in 2022, 15.8% of the employed population was employed in the agricultural sector, amounting to 4,866,000 individuals. This figure represents a decline of 82,000 compared to the previous year. However, data from 2024 indicates that despite the decline in the agricultural sector's share of total employment to 14.8%, there was an increase of 132,000 in the absolute number of employed individuals compared to the previous year (TurkStat, 2025). This persistent downward trend is attributed to a number of factors, including mechanization, industrialization, urbanization, and the fragmentation of agricultural land through inheritance (Görmüş, 2019). The annual fluctuations in the absolute values of agricultural employment (e.g., the decline in 2022 and the increase in 2024) reveal that, despite the long-term downward trend in the sector's share of total employment, it functions as a shock absorber (buffer) for the overall labor market (Olhan, 2011). This phenomenon underscores the sensitivity of agricultural employment decisions to short-term fluctuations in profitability and changes in support policies. This sensitivity may potentially exhibit an asymmetric structure, as evidenced by the ability to expeditiously attract labor during periods of contraction in other sectors. However, the capacity to generate new permanent employment opportunities or release existing labor in response to increased support may be comparatively diminished. Furthermore, structural issues, such as high levels of informality and underreported unemployment in the sector, suggest that the employment response to policy support may not be linear (Us & Akbıyık, 2023).

Türkiye has a long history of active government policies targeting the agricultural sector. These policies utilize a wide range of tools to achieve various objectives, including increasing production, raising self-sufficiency levels in food, supporting farmers' incomes, and promoting rural development (Baysuğ, 2017; Çelik, 2022; Demirdöğen et al., 2016; Konyali & Oraman, 2019). The strategic plans formulated by the Ministry of Agriculture and Forestry prioritize enhancing the competitiveness of the agricultural sector, optimizing production efficiency, and ensuring environmental sustainability as paramount policy objectives (T.R. Ministry of Agriculture and Forestry, 2025). Despite the evolution of agricultural support policies from direct price supports and input subsidies to decoupled and direct income support schemes, production-based supports remain a significant component of these policies (Kizilaslan et al., 2007; Tan et al., 2016).

The employment effects of agricultural policy supports frequently exhibit a complex and occasionally paradoxical pattern, contrary to the anticipated positive correlation (Table 1). While policy expectations suggest that increases in subsidies will protect agricultural employment by increasing farmer incomes and sectoral attractiveness, empirical findings indicate that this relationship is neither linear nor unidirectional (Demirdogen et al., 2022).

Table 1. Potential asymmetric channels of agricultural support shocks on employment decisions

Impact Channel	Expected Impact of Positive Support Shock	Expected Impact of a Negative Support Shock	Potential Source of Asymmetry
Production Level	Increase in labor demand with increased production	Decline in labor demand due to reduced production	Asymmetry of production responses
Income vs. Substitution Effects (On-farm, Off-farm labor)	Income effect: reduction in labor supply; Substitution effect (Coupled support): increase in on-farm labor	Income effect: increase in labor supply (compensating for loss of income); Substitution effect (Coupled support): decrease in on-farm labor	Relative magnitude of impacts, off-farm market conditions
Hiring/Firing Costs & Labor Market Rigidities	Slow recruitment (if there is uncertainty)	Rapid layoffs	Asymmetry of adjustment costs
Mechanization	Increased investment in labor-saving technology (may reduce employment in the long run)	Slowdown in mechanization investments	The irreversibility of technological change
Coupled vs. Decoupled Support Distinction	Coupled support: Increase in on-farm labor; Decoupled support: Increase in the probability of off-farm labor/on-farm uncertainty	Coupled support: Reduction in on-farm labor; Decoupled support: Potential increase in labor supply due to wealth reduction	Different behavioral effects of the type of support

Source: Ahearn et al., 2006; Ding et al., 2024; Garrone et al., 2019; Peng et al., 2022; Ray et al., 2025

Although positive shocks to agricultural support, such as increases in subsidies, have the potential to increase production and employment, the impact of these increases may fall short of expectations due to structural constraints (Bayramoğlu et al., 2021). The mechanisms underlying these interactions are particularly

evident in the following phenomena: the reduction in net labor demand due to support measures promoting capital-intensive technologies; the absence of direct impact on employment of decoupled payments not linked to production and employment conditions; and the acceleration of consolidation of large-scale farms, resulting in a shift away from labor-intensive production patterns. (Berlinschi et al., 2012; Caunedo & Kala, 2021; Garrone et al., 2019; Rizov et al., 2013). Conversely, the reduction of subsidies in a sector with a high degree of reliance on such support could result in more abrupt and disproportionate employment declines, particularly as unproductive farms are compelled to cease operations. This downward asymmetry is further exacerbated by constraints on labor mobility, limited alternative employment opportunities in rural areas, and high sectoral exit costs. This process necessitates an evaluation of the impact on employment, encompassing not only the quantity of support but also the design, orientation, and implementation context of that support.

In order to comprehensively evaluate the policy ramifications of such structural asymmetries, it is imperative to depend not solely on theoretical assumptions but also on empirical evidence from diverse countries and regions. In this regard, studies conducted at the national and international levels have demonstrated that the effects of agricultural support on employment can vary significantly depending on the type of support, the context of implementation, market structure, and technology level. Dall'erba and van Leeuwen (2006), conducted a study encompassing 109 EU regions and found that support for animal production had no significant impact on employment. However, they determined that structural funds could support the regional employment share of the agricultural sector. A growing body of research is beginning to elucidate the more pronounced effects of mechanization policies on employment. As Nagarjuna et al. (2024) emphasize, the advent of mechanization in agriculture has the potential to effect profound changes not only in the physical production sphere but also in the labor market. The extant research indicates that, while contemporary agricultural technologies reduce the demand for labor, they concomitantly engender new employment opportunities in domains such as maintenance, data analysis, and the administration of digital agricultural systems. However, the realization of these prospects necessitates a workforce that is proficient in technical skills. Moreover, the digital divide can impede the capacity of small farmers to reap the benefits of mechanization, consequently influencing the regional and social distribution of employment opportunities. In Türkiye, studies have underscored the historical significance of agriculture in employment and the ramifications of policy shifts on small farms and rural poverty (Gülçubuk & Aluftekin, 2006). A number of studies have examined the effects of agricultural support on agricultural output (Akça & Altuntaş, 2022). A similar study by Guvenerek et al. (2022) examined the effect of price difference payment support, one of the agricultural support tools, on the production of selected product groups.

To accurately assess the impact of agricultural support programs on employment, comparative and structurally disaggregated analyses are needed at both the national and international levels. The Organization for Economic Co-operation and Development (OECD) has developed a set of four key indices to measure the effects of agricultural policies on producers, consumers, and public finances. These indices employ a standardized and comparable methodology (OECD, 2024). These indices systematically reveal the level, composition, transfer mechanisms, and policy orientation of agricultural support. Within the analytical framework established by the OECD, the Producer Support Estimate (PSE), which measures direct and indirect gross monetary transfers to producers, plays a central role. The PSE is defined as the total value of monetary transfers to producers through consumers and taxpayers (Karapici et al., 2024)**.** It is particularly well-suited for examining the effects of policies on producer income and employment. This because it includes both indirect interventions, such as market price support (e.g., intervention purchases and import protection), and direct budget transfers (e.g., area-based, product-based, input-based, and income support payments). This aspect renders it particularly well-suited for the examination of the effects on producer incomes and employment. Furthermore, the Consumer Support Estimate (CSE) analyzes the financial burden on consumers or the potential benefits of implemented policies, while the General Services Support Estimate (GSSE) covers expenditures on general public services such as R&D, infrastructure, and oversight directed toward the sector. Conversely, the Total Support Estimate (TSE) is a comprehensive metric that reflects the total financial support provided by a country to its agricultural sector, thereby offering a more holistic assessment of the economic and budgetary outcomes of agricultural policies.

A thorough examination of Türkiye's PSE value reveals that gross farm income stood at approximately 11% during the 2021–2023 period. This figure signifies a substantial decline when compared to the 40% level recorded during the 2000–2002 period. The observed trend points to a convergence of Türkiye's economic performance towards the OECD average, as depicted in Figure 1. Approximately 68% of the total support provided during this period consisted of market price support (MPS) implemented through tariffs, accompanied by the reduction of export debts and capital transfers to public enterprises. Direct budget transfers to producers are allocated in the form of product-based premium payments, area-based support, and input subsidies (e.g., diesel fuel, fertilizers, and agricultural insurance). GSSE accounts for 21% of agricultural support, which exceeds

the OECD average of 14%. This category includes rural infrastructure investments, primarily irrigation systems, and marketing activities. The aggregate level of support furnished to the agricultural sector (TSE) persists at 1% of GDP, which exceeds the OECD average (0.6%). However, this ratio has diminished considerably compared to the 5.4% recorded at the onset of the 2000s, due to the general economic growth outpacing the growth rate of the agricultural sector (OECD, 2024).

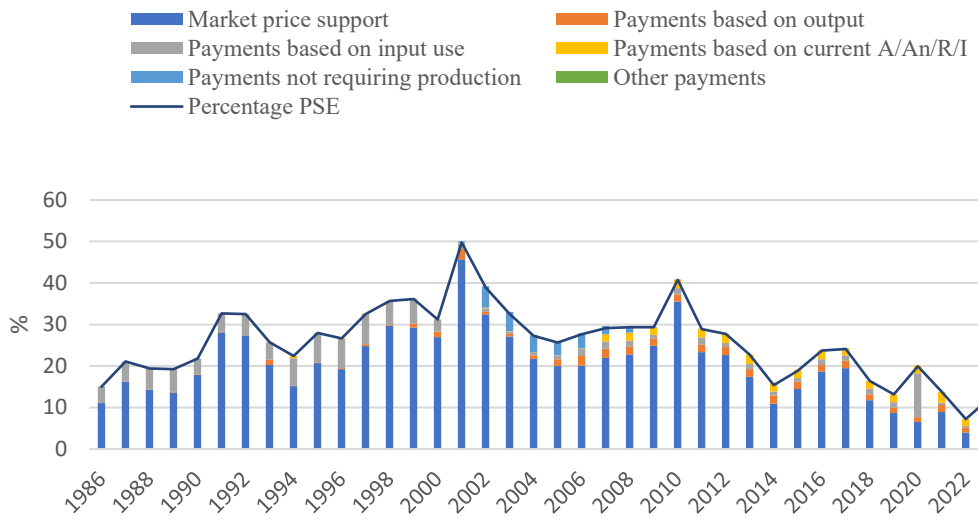

Figure 1. Trends in Türkiye's PSE composition relative to gross farm receipts, 1986–2023 (OECD, 2024)

Among the indicators developed by the OECD, PSE is particularly noteworthy, as it not only captures the magnitude of policy interventions but also reflects the structural characteristics of support measures and the overall orientation of agricultural policies. In the literature, the PSE indicator has been employed to evaluate the impact of agricultural support on the gap between domestic and world prices (Mullen et al., 2004), to analyze the trade-distorting effects of different forms of support (Blandford et al., 2007), to examine the relationship between levels of development, fiscal indicators, and PSE (Siudek & Zawojska, 2011), to compare the effects of PSE on productivity differences between exporting and importing countries (Eslami & Sherafatmand, 2013), to investigate the impact of PSE and the Nominal Rate of Assistance (NRA) on agricultural exports (Yanıkkaya & Koral, 2013), to assess its effects on farm incomes and to enhance policy transparency (Boháčková, 2015), to compare Türkiye's PSE levels with those of OECD countries (Semerci̇, 2019), to analyze the effects of exchange rate fluctuations on PSE (Demirdöğen, 2020), and to examine the impact of agricultural support on agricultural productivity (Karakaya, 2023). While academic studies recognize the PSE as an indispensable tool for comparative policy analysis, they also highlight its limitations as a standalone measure. In this context, several critiques regarding the PSE index have been raised in the literature. Research indicates that the PSE does not adequately capture qualitative changes in agricultural policy frameworks (Tangermann, 2005). For instance, when a country transitions from price interventions to decoupled direct payments, the overall agricultural policy may become less market-distorting. However, as long as the total level of transfers remains constant, the PSE value will not be altered. As Oskam and Meester (2006) have noted, an exclusive focus on the total PSE figure may result in the oversight of crucial policy reforms. Consequently, the extant literature suggests that PSE data be disaggregated into its component parts for the purpose of analysis. Indeed, OECD reports also present countries' PSE components (e.g., the distinction between policies' disruptive effects on production and trade), enabling the tracking of transformations in the support structure (Tangermann, 2005). The second salient issue that merits deliberation is the impact of global market conditions on the PSE. In the market price support, which constitutes the primary component of the PSE, domestic prices are juxtaposed with international prices (border prices). Consequently, when a country's domestic currency devalues or appreciates in relation to international currencies, support indicators are influenced by this change. As a result of this effect, support may decrease while support indicators increase, or support may increase while support indicators decrease (Demirdöğen, 2020). A third point of criticism is that the PSE measures gross transfers rather than economic welfare effects. Therefore, even in the presence of a high PSE, it remains unclear how this is fully reflected in agricultural productivity or farmer welfare. Furthermore, given the indirect nature of the PSE's impact on employment, a cautious interpretation of this relationship is imperative. In this study, taking into account the aforementioned limitations, the effects of the PSE on agricultural employment were modeled within an asymmetric dynamic

structure, together with complementary variables, and the results were interpreted in this context. The Nonlinear Distributed Lag Autoregressive (NARDL) model provides an appropriate framework for empirically testing these asymmetric relationships.

A review of the literature on NARDL and other nonlinear models reveals a wide range of applications in the field of agricultural economics for analyzing various relationships. These models have been employed to investigate the asymmetric effects of input prices (such as diesel and fertilizers) on farm-gate prices (e.g., wheat) (Uzel et al., 2025), the asymmetric causality between agricultural support payments and agricultural production (Sağdıç & Çakmak, 2021), the asymmetric impacts of agricultural support and credits on agricultural output (Gezer & Gezer, 2022), the relationship between unemployment and output in the context of Okun's Law (Akkoyunlu, 2024), and the effects of positive and negative shocks in agricultural product prices on agricultural growth (Kashif et al., 2023).

The extant literature has largely addressed asymmetric effects within the framework of production volume or price dynamics. The NARDL approach has been applied in the Turkish agricultural sector primarily for macroeconomic indicators such as prices, foreign trade conditions, or credit supply. However, to date, the extant literature lacks a comprehensive and systematic empirical study that employs the same methodological framework to test the short- and long-term asymmetric elasticities of positive and negative shocks observed in the OECD PSE index on agricultural employment in Türkiye. This lacuna in the extant literature results in an absence of evidence-based policy outcomes, which are imperative for the effective design of agricultural support policies that increase employment. The present study endeavors to address a substantial methodological and empirical lacuna in the Turkish agricultural economy literature. The findings offer valuable insights to policymakers on formulating more effective agricultural support policies for achieving employment targets, particularly in the context of ongoing structural transformations in the agricultural sector and at the macroeconomic level. The study also provides significant insights for international discussions and comparative analyses of agricultural support policies by focusing on the PSE indicator.

In consideration of the aforementioned information, the main objective of this study is to empirically examine the potential short- and long-term asymmetric effects of agricultural policy support measured by the OECD PSE index on agricultural employment levels in Türkiye, using the NARDL cointegration methodology. Cointegration refers to a statistical relationship in which two or more variables exhibit a common long-term trajectory, indicating that they move together over time despite short-term deviations.

The fundamental research hypotheses are delineated below as H1, H2, and H3. These hypotheses form the primary focus of the study. However, the asymmetric effects of other variables included in the model, such as agricultural credit and agricultural imports, on agricultural employment have also been analyzed within the framework of the NARDL model estimation results.

H1: There is a statistically significant long-term (symmetric or asymmetric) cointegration relationship between the OECD PSE index and agricultural employment in Türkiye.

H2: The long-term effect of positive changes in the OECD PSE index on agricultural employment is significantly different from the long-term effect of negative changes in the OECD PSE index.

H3: The short-term dynamic effects of positive changes in the OECD PSE index on agricultural employment are significantly different from the short-term dynamic effects of negative changes in the OECD PSE index.

MATERIALS AND METHODS

Materials

The primary data set for this study consists of annual time series for agricultural employment, producer support estimate, agricultural credit volume, agricultural product exports, agricultural product imports, and the share of the agricultural sector in GDP for the period 1986–2023 (Table 2). The data were obtained from the databases of the Turkish Statistical Institute (TurkStat), the Presidency of the Strategic and Budgetary Office of the Republic of Türkiye (SBB), the Turkish Banking Association (TBB), and the OECD. To convert monetary values to real values, the GDP deflator was utilized, setting 2009 as the base year at 100.

Table 2. Definitions and data sources of the variables used in the study

Variable name	Description	Unit	Data Source
TIST	Agricultural Employment	Thousand Persons	(TurkStat, 2025)
RPSE	Real Producer Support Estimate	Million TL	(OECD, 2025)
RTK	Real Agricultural Credit	Million TL	(TBB, 2025)
RIHR_TAR	Real Agricultural Product Exports	Million TL	(TurkStat, 2025)
RITH_TAR	Real Agricultural Product Imports	Million TL	(TurkStat, 2025)
TGSYHP	Share of Agriculture in GDP	%	(SBB, 2025; TurkStat, 2025)

Methods

In this study, the asymmetric effects of PSE and other complementary economic variables on agricultural employment in Türkiye were analyzed using the NARDL model. EViews software was used in the analysis process.

The methodological process is presented in the following step-by-step manner:

Preparation of the data set

To facilitate the interpretation of regression coefficients in terms of elasticity and to mitigate the impact of heteroscedasticity (Gujarati, 2003), natural logarithm transformations were implemented on the variables of agricultural employment, real PSE, real agricultural credit, real agricultural product exports, and real agricultural product imports. Conversely, the share of agriculture in GDP was not subjected to logarithmic transformation due to its status as a ratio variable.

Stationarity tests

The degree of integration of time series is a critical factor in cointegration analyses and ARDL/NARDL modeling processes, as evidenced by research conducted by Pesaran et al. (2001) and Shin et al. (2014). Therefore, before advancing to the modeling stage, the stationarity levels of the variables were assessed using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The ADF test (Dickey & Fuller, 1979; Said & Dickey, 1984) is a parametric method that tests the presence of a unit root by estimating a regression model that accounts for the lagged values of the series, while the PP test (Phillips & Perron, 1988) primarily estimates a Dickey-Fuller type regression equation. However, after this estimation, the standard errors are revised through the implementation of non-parametric adjustments. These adjustments are employed to address potential issues of autocorrelation and heteroskedasticity present within the error terms of the series. In this study, critical values at the 1%, 5%, and 10% significance levels were employed for both tests, and the series were analyzed at both the level and first difference levels. The findings of the study indicate that none of the series are integrated at the I(2) level, thereby satisfying the suitability condition for ARDL/NARDL modeling (Göksü & Balkı, 2023). An I(2) process refers to a time series that achieves stationarity after being differenced two times.

Determination of the lag structure

In this study, the maximum lag length was set to 2, a choice that was made for the purposes of minimizing data loss and preventing over-parameterization of the model due to the annual frequency of the series. The Akaike Information Criterion (AIC) was employed to select the lag structure.

The basic structure of the NARDL model

In this study, the logarithm of agricultural employment (LN_TIST) was used as the dependent variable. The independent variables were, in order, the logarithm of producer support estimate (LN_RPSE), the logarithm of agricultural exports (LN_RIHR_TAR), the logarithm of agricultural imports (LN_RITH_TAR), the logarithm of agricultural credit volume (LN_RTK), and the share of agriculture in GDP (TGSYHP).

The independent variables have been separated into positive and negative components and incorporated into the model to accommodate potential asymmetric effects. To illustrate, the decomposition for the LN_RPSE variable is defined as follows (Eq.1):

$$LN_RPSE_t^+ = \sum_{j=1}^{t} \max\left(\Delta LN_RPSE_j, 0\right), LN_RPSE_t^- = \sum_{j=1}^{t} \min\left(\Delta LN_RPSE_j, 0\right) \quad \text{(Eq.1)}$$

Similar separations have been performed for the LN_RIHR_TAR, LN_RITH_TAR, LN_RTK, and TGSYHP variables.

The short-run dynamics and error correction representation of the NARDL model used in this study is expressed as follows (Eq.2)(Pesaran et al., 2001; Shin et al., 2014).

$$\Delta LN_TIST_t = \alpha_0 + \alpha_1 LN_TIST_{t-1} + \alpha_2 LN_RPSE_{t-1}^+ + \alpha_3 LN_RPSE_{t-1}^- + \alpha_4 LN_\text{RIHR_TAR}_{t-1}^+ + \alpha_5 LN_\text{RIHR_TAR}_{t-1}^- + \alpha_6 LN_\text{RITH_TAR}_{t-1}^+ + \alpha_7 LN_\text{RITH_TAR}_{t-1}^- + \alpha_8 LN_\text{RTK}_{t-1}^+ + \alpha_9 LN_\text{RTK}_{t-1}^- + \alpha_{10}\text{TGSYHP}_{t-1}^+ + \alpha_{11}\text{TGSYHP}_{t-1}^- + \sum_{i=1}^{p} \beta_i \Delta LN_TIST_{t-i} + \sum_{i=0}^{q1} (\delta_i^+ \Delta LN_RPSE_{t-i}^+ + \delta_i^- \Delta LN_RPSE_{t-i}^-) + \sum_{i=0}^{q2} (\gamma_i^+ \Delta LN_\text{RIHR_TAR}_{t-i}^+ + \gamma_i^- \Delta LN_\text{RIHR_TAR}_{t-i}^-) + \sum_{i=0}^{q3} (\tau_i^+ \Delta LN_\text{RITH_TAR}_{t-i}^+ +$$

$\tau_i^- \Delta LN_\text{RITH_TAR}_{t-i}^-) + \sum_{i=0}^{q4}(\emptyset_i^+ \Delta LN_\text{RTK}_{t-i}^+ + \emptyset_i^- \Delta LN_\text{RTK}_{t-i}^-) + \sum_{i=0}^{q5}(\varphi_i^+ \Delta\text{TGSYHP}_{t-i}^+ + \varphi_i^- \Delta\text{TGSYHP}_{t-i}^-) + \varepsilon_t$ (Eq.2)

In the equation, the α_1 represents the speed of the model's return to long-run equilibrium, $\alpha_2 - \alpha_{11}$ represents the long-run effects of the positive and negative components of the independent variables, β_i represents the short-run effects of the lagged differences of the dependent variable, and $\delta_i^+, \delta_i^-, \gamma_i^+, \gamma_i^-, \tau_i^+, \tau_i^-, \emptyset_i^+, \emptyset_i^-, \varphi_i^+, \varphi_i^-$ represents the short-run effects of the positive and negative components of the independent variables.

Cointegration Test

In order to examine whether the model exhibits a long-run relationship, the Bounds testing approach (Pesaran et al., 2001) was employed, utilizing both the F-Bounds and t-Bounds tests. Within this framework, the null hypothesis (H_0) of no cointegration and the alternative hypothesis (H_1) of the presence of cointegration were tested. The F-statistic and the t-statistic of the lagged level of the dependent variable (LN_TIST_{t-1}) were compared against the critical bounds values (I(0), I(1)) proposed by Pesaran et al. (2001) to determine whether a cointegrated long-run relationship exists within the model.

Asymmetric tests

To determine whether there is a significant difference (asymmetric effect) between positive and negative components within the model, the Wald test was employed for both the long-term and short-term contexts (Shin et al., 2014). In this context, the equality of positive and negative level coefficients in the long term and the equality of the total effects of positive and negative difference terms in the short term were evaluated using the Wald test.

Model diagnostic tests

A suite of diagnostic tests was employed to assess the validity of the model and its adherence to fundamental assumptions (Kocaman, 2024). The Jarque-Bera test was employed to assess the normality of error terms, the Breusch-Pagan-Godfrey and ARCH tests were utilized to ascertain the presence of heteroscedasticity (varying variance), the Breusch-Godfrey LM test was implemented to determine the presence of autocorrelation, and the Ramsey RESET test was used to test the accuracy of the model's functional form. Under the empirical evaluations conducted, it was determined that the model's fundamental assumptions are met at the 5% significance level, thereby affirming its reliability.

RESULTS AND DISCUSSION

The descriptive statistics of the analyzed variables reveal that the data sets mostly deviate from normal distribution (Table 3). The majority of the variables—particularly real agricultural exports, imports, and share of agriculture in GDP —demonstrate positive skewness (right-skewed distribution). This finding aligns with the observation that the means are elevated above the medians, suggesting that the sporadic high values recorded in the series are contributing to an upward shift in the mean. Notably, real agricultural product imports and real agricultural credits exhibit high standard deviations and coefficient of variation, with the coefficient of variation for real agricultural product imports approximating 0.813, suggesting substantial fluctuations in the series. Furthermore, real producer support estimate, real agricultural product imports, and exports manifest leptokurtic (peak-shaped and heavy-tailed) distributions, underscoring the impact of extreme values, while other variables exhibit a more platykurtic (flat-tailed) structure.

Table 3. Descriptive statistics of the variables analyzed in the study

	TIST	RPSE	RIHR_TAR	RITH_TAR	RTK	TGSYHP
Average	6786.6050	25892.8100	9189.7750	9872.7500	20558.4600	10.5837
Median	6120.0000	27375.5100	7869.4740	6984.1490	17388.6300	9.0661
Maximum	9259.0000	46966.9700	19850.1600	33687.8400	43031.5400	19.5126
Minimum	4695.0000	11987.5000	4536.5630	1506.9060	4969.9890	5.5338
Standard Deviation	1684.2640	6546.4760	3956.1510	8023.0430	11295.7000	4.3268
Skewness	0.1710	0.4596	1.3623	1.4006	0.4755	0.5950
kurtosis	1.3153	4.3940	4.0279	4.1356	1.9771	1.8494

The time series plots presented in Figure 2 reveals that the indicators under scrutiny exhibit substantial structural and cyclical dynamics over the 1986–2023 period. A decline in both agricultural employment and the share of agriculture in GDP was observed throughout the period under study. The decline in agricultural employment accelerated notably in the early 2000s, whereas the share of agriculture in GDP followed a more

stable and gradual downward trajectory. Numerous studies on Türkiye have analyzed this pattern in the existing literature. For instance, in their study, Hatunoğlu and Eldeniz (2012) examined data from 1990 to 2011 and demonstrated that the decline in agricultural employment had accelerated and that the sector's share in GDP had fallen below 10%. A similar approach was taken in a study by Çiçen (2022), which analyzed structural transformations in Türkiye's labor market during the 2000s. The study indicated a decline in the proportion of the agricultural sector to the total workforce, reaching 36% in the year 2000. Furthermore, the study indicated that during periods of domestic economic crises in Türkiye, particularly in 1994 and during the 2000–2001 crise, there was a significant increase in labor mobility between the agricultural and services sectors.

In contrast, the indicators for real agricultural exports and imports have exhibited an accelerating upward trend, particularly in the post-2005 period. Since 2007, real agricultural exports have exhibited a steady increase, indicative of a heightened integration with international markets. Conversely, real agricultural imports have demonstrated a consistent upward trend, accompanied by notable volatility in recent years. In this context, the extant literature also highlights the influence of macroeconomic factors on Türkiye's agricultural trade dynamics. For instance, Karakaş and Erdal (2017) found that Türkiye's agricultural trade is directly affected by volatility in the real effective exchange rate. At times, these effects contribute to imbalances in agricultural import and export indicators.

Following a pronounced peak in 1997, accompanied by a subsequent decline, real agricultural credits embarked on a robust and protracted upward trajectory in the post-2005 era. Keskin and Çıkıryel's (2024) study similarly found that agricultural financing in Türkiye exhibited a positive growth trajectory during the period 2005Q1–2023Q4, with this trend exerting a significant and positive impact on agricultural GDP. In contrast, the real producer support estimate does not exhibit a clear long-term trend, though it displays notable peaks in certain years and reflects a high degree of volatility, capturing the composite effects of shifting policy components over time. Chalajour and Nashroodkoli (2022) reported that the level of producer support in Türkiye has fluctuated considerably over the years, particularly following the abolition of the direct payment system in 2009. This abolition led to a restructuring of policy components and resulted in periods of both increases and decreases in the PSE. This has contributed to an absence of a clear long-term trend and the emergence of a pronounced pattern of volatility driven by evolving policy dynamics.

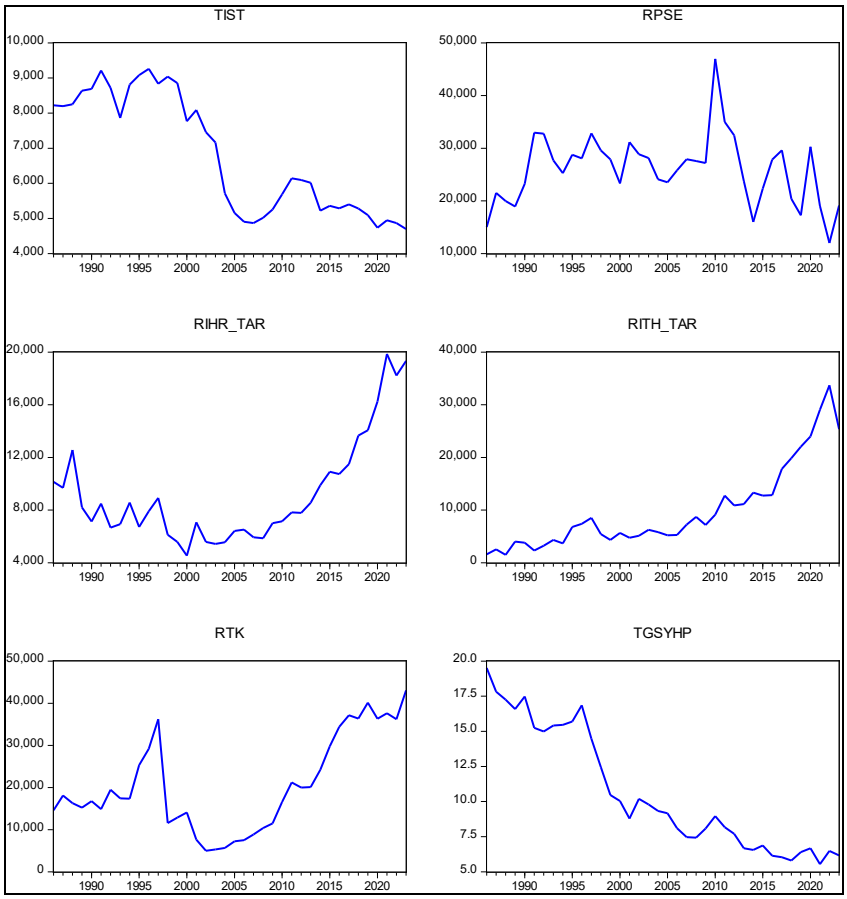

Figure 2. Time series graphs of variables (1986-2023)

In order to ascertain the stationarity properties of the variables—a fundamental prerequisite for NARDL analysis—this study implemented the ADF and PP unit root tests on all series (Table 4). The findings suggest that the variables LN_TIST, LN_RIHR_TAR, LN_RTK, and TGSYHP manifest unit roots at the level, yet become stationary at the first difference at the 1% significance level. Consequently, these variables are designated as I(1). The variable LN_RITH_TAR was found to be non-stationary at the level in the model with constant, but exhibited stationarity at the 5% level in the model with constant and trend, according to both the ADF test ($p \leq 0.05$) and the PP test ($p \leq 0.05$). In contrast, the variable LN_RPSE was found to be stationary at a 1% significance level in both tests ($p \leq 0.01$). Accordingly, this variable is classified as I (0). The ADF and PP test results were generally consistent, and the fact that none of the variables were integrated of order two (I(2)) supports the appropriateness of employing the NARDL approach (Pesaran et al., 2001).

Table 4. Stationarity test of the variables included in the analysis

				Level Value			
		LN_TIST	LN_RPSE	LN_RIHR_TAR	LN_RITH_TAR	LN_RTK	TGSYHP
PP	Constant	-0.5086 (0.8606)	-3.7086 (0.0080) ***	-0.2789 (0.9186)	-1.3508 (0.5955)	-1.0793 (0.7137)	-2.2237 (0.2017)
	Constant and Trend	-2.1803 (0.4861)	-3.8252 (0.0262) **	-1.6593 (0.7490)	-3.9861 (0.0180) **	-1.3865 (0.8485)	-2.0370 (0.5625)
				1. Difference Value			
		d(LN_TIST)	d(LN_RPSE)	d(LN_RIHR_TAR)	d(LN_RITH_TAR)	d(LN_RTK)	d(TGSYHP)
	Constant	-4.9079 (0.0003) ***	-10.5770 (0.0000) ***	-8.0521 (0.0000) ***	-9.6715 (0.0000) ***	-5.7762 (0.000) ***	-5.9063 (0.0000) ***
	Constant and Trend	-4.8616 (0.002) ***	-16.9511 (0.0000) ***	-17.6514 (0.0000) ***	-9.5241 (0.0000) ***	-5.8492 (0.0001) ***	-6.3130 (0.0000) ***
				Level Value			
ADF	Constant	-0.4922 (0.8815)	-3.7732 (0.0068) ***	-0.6503 (0.8468)	1.4702 (0.9988)	-0.961 (0.7569)	-1.9935 (0.2883)
	Constant and Trend	-2.7384 (0.2284)	-3.9564 (0.0193) **	-1.6593 (0.7490)	-3.8731 (0.0235) **	-1.3602 (0.8561)	-1.9022 (0.6332)
				1. Difference Value			
	Constant	-4.9192 (0.0003) ***	-6.7638 (0.0000) ***	-7.8688 (0.0000) ***	-3.0855 (0.0393) **	-5.7785 (0.0000) ***	-5.9009 (0.0000) ***
	Constant and Trend	-4.8723 (0.002) ***	-7.0243 (0.0000)	-8.6572 (0.0000) ***	-3.5919 (0.0489) **	-5.8490 (0.0001) ***	-5.9855 (0.0001) ***

, **, * indicate 1%, 5% and 10% significance level respectively.*

In the cointegration analysis (Table 5), the calculated F-statistic (5.64) exceeds the upper bound critical value of I (1) at the 1% significance level (3.86). This finding provides strong evidence for the existence of a long-run cointegration relationship among the variables. Furthermore, the t-statistic (-4.96) associated with the lagged level of the dependent variable is more negative than the I (1) critical value at the 10% significance level (-4.69). This finding is consistent with the presence of a long-run cointegration relationship and indicates that the long-run structure of the model is statistically significant.

The long-term coefficient estimates presented in Table 6 for the NARDL model indicate that the level of agricultural employment in Türkiye exhibits asymmetric and flexible responses to various macroeconomic and sectoral determinants. When positive shocks are taken into account, an increase in producer support estimates (LN_RPSE_POS) is observed to have a statistically significant and positive effect on agricultural employment. A 1% increase in producer support estimates is estimated to increase agricultural employment by approximately 0.40% on average (coefficient = 0.3958; $p \leq 0.05$). A parallel increase in real agricultural credit volume (LN_RTK_POS) has been shown to result in an approximate 0.40% increase in employment (coefficient = 0.3967; $p \leq 0.05$).

Table 5. Results of the cointegration (long run relationship) test

NARDL (1, 1, 2, 2, 2, 0, 0, 2, 0, 2, 1)								
k	**m**	**Test statistic**	**Test statistic**	**Test statistic**	**F- critical value**		**t- critical value**	
					I (0)	**I (1)**	**I (0)**	**I (1)**
10	2	F-statistic	5.636869	10%	1.83	2.94	-2.57	-4.69
				5%	2.06	3.24	-2.86	-5.03
		t-statistic	-4.959268	2.50%	2.28	3.50	-3.13	-5.34
				1%	2.54	3.86	-3.43	-5.68

k and m represent the number of independent variables and the maximum lag length, respectively.

A review of the extant literature reveals a paucity of consensus on the impact of agricultural support on agricultural employment. The findings do, however, vary according to the types of support and regional differences. Dall'erba and van Leeuwen's (2006) spatial econometric analysis, conducted as part of the European Union, the Common Agricultural Policy (CAP), and structural fund support, revealed the impact of these policies on changes in agricultural employment in European regions. The analysis demonstrated that this impact exhibited heterogeneous results depending on regional and neighborhood dynamics. In this context, the results of the current study are consistent with the extant literature, which points to the role of certain support mechanisms in increasing agricultural employment. However, it is imperative to acknowledge that the efficacy of support may be subject to variation depending on the implementation strategy and the regional structure. When examining the situation in terms of agricultural credit, the extant literature reports conflicting findings regarding the effects of agricultural credit on agricultural employment. Rios e Silva and Arruda's (2019) PVAR analysis, conducted at the state level in Brazil, revealed a positive relationship between increases in agricultural credit and agricultural employment in labor-intensive agricultural regions. Conversely, in capital-intensive and technology-driven regions, credit increases were found to have a negative effect on agricultural employment. This finding indicates that the impact of agricultural credit may be subject to variation depending on the regional production structure and labor intensity.

On the other hand, a 1% increase in agricultural exports (LN_RIHR_TAR_POS) was found to reduce employment by approximately 1% (coefficient = -1.0026; $p \leq 0.10$). The coefficients associated with both positive (LN_RITH_TAR_POS) and negative (LN_RITH_TAR_NEG) shocks in imports were found to be statistically insignificant ($p \geq 0.05$), thereby indicating that imports do not have a significant long-term effect on agricultural employment. A review of the extant literature reveals findings that are analogous to those of the present study. Remeikiene et al. (2018) found that increases in agricultural exports had negative effects on employment and labor force indicators in the agricultural sector in their study on the Baltic countries. However, He (2020) stated in his study on the US that increases in agricultural exports had positive and significant effects on farm employment, contradicting the research findings. The production structure, technology level, and export product pattern of countries are thought to be decisive factors in these different results. The shift toward a more capital-intensive production structure, changes in the input composition, and the substitution of labor-intensive domestic production for external demand are likely to contribute to this effect.

The positive and statistically significant coefficient of the TGSYHP_NEG variable at the 5% level of significance (coefficient =0.1056; $p \leq 0.05$) indicates that a one-percentage-point decrease in the share of agriculture in GDP leads to an approximate 11.14% ($100 \times (e^{0.1056} - 1)$) increase in agricultural employment in the long run. This finding suggests that during periods of structural transformation in the agricultural sector, agriculture functions as an "employment buffer," with a tendency for labor to shift back into the sector, particularly during times of heightened economic vulnerability. This outcome aligns with the extant literature that characterizes agriculture as a "sector of last resort" for low-skilled labor (Timmer, 1997). For instance, following the 2001 economic crisis, the Turkish economy exhibited an average annual growth rate of 7%, yet the slowdown in growth in 2008 and the contraction of 4.7% in 2009 coincided with a significant increase in agricultural employment. Specifically, the number of individuals employed in agriculture increased by approximately 8% in 2009 compared to 2007, reaching 5.254 million. This phenomenon suggests that the agricultural sector functions as a temporary refuge for employment during periods of economic downturn. In periods of economic downturn, when employment opportunities in other sectors become limited, a segment of the labor force tends to revert to agriculture. However, with the subsequent economic recovery, these individuals often transition back to non-agricultural sectors (Olhan, 2011).

The results of the Wald test applied to assess the symmetry of the long-term coefficients of the NARDL model indicate that some variables in the model have asymmetric long-term effects on agricultural employment (Table 6). Specifically, the null hypothesis that the long-term effects of positive and negative shocks in the real producer support estimate are equal has been rejected at the 5% significance level (Wald statistic = 7.1224,

p≤0.05). This result indicates the presence of a significant long-term asymmetry for the LN_RPSE variable. In a similar vein, the Wald test applied to real agricultural credits rejected the hypothesis that the coefficients are symmetric at the 1% significance level (Wald statistic = 9.9570, p ≤0.01). This analysis demonstrated that the effects of LN_RTK on agricultural employment differ significantly depending on the direction of the effects. The Wald test for the share of agriculture in GDP revealed a significant difference between positive and negative changes (Wald statistic = 3.5831, p≤0.10), supporting a long-term asymmetry for TGSYHP. In contrast, no statistically significant difference was found between the long-term effects of positive and negative shocks for real agricultural product exports and real agricultural product imports.

Table 6. Long-run coefficient estimates in the NARDL model

Long Run Coefficients				
Variable	**Coefficient**	**Std. Error**	**t-statistic**	**Probability**
LN_RPSE_POS	0.3958**	0.1339	2.9551	0.0131
LN_RPSE_NEG	-0.0365	0.1804	-0.2025	0.8432
LN_RIHR_TAR_POS	-1.0026*	0.4952	-2.0245	0.0679
LN_RIHR_TAR_NEG	-0.6476	0.3631	-1.7835	0.1021
LN_RITH_TAR_POS	-0.0076	0.1541	-0.0490	0.9618
LN_RITH_TAR_NEG	-0.1656	0.1775	-0.9328	0.3709
LN_RTK_POS	0.3967**	0.1611	2.4621	0.0316
LN_RTK_NEG	-0.0039	0.1273	-0.0305	0.9762
TGSYHP_POS	-0.0386	0.0987	-0.3908	0.7034
TGSYHP_NEG	0.1056**	0.0368	2.8701	0.0152
Long Run Wald Test Results				
W_{LRLN_RPSE}: 7.1224 (0.0183) **		W_{LRLN_RTK}: 9.9570 (0.0070) ***		
$W_{LRLN_RIHR_TAR}$: 0.4185 (0.5281)		$W_{LRTGSYHP}$: 3.5831 (0.0792) *		
$W_{LRLN_RITH_TAR}$: 0.4635 (0.5071)				
Diagnostic Tests				
Jarque-Bera: 0.7352 (0.6924)		ARCH Heteroskedasticity: 0.1043 (0.7488)		
Breusch-Godfrey LM Autocorrelation: 0.8805 (0.4397)		Ramsey RESET: 1.1731 (0.2984)		
Breusch-Pagan-Godfrey Heteroskedasticity: 1.1869 (0.3777)				

, **, * indicate 1%, 5%, and 10% significance level respectively.*

The results of the diagnostic test, as presented in Table 6, indicate the continued validity of the estimated NARDL model with respect to its fundamental assumptions. Initially, the Jarque-Bera test was employed to evaluate the normality of the model residuals. This analysis yielded a result of JB = 0.7352 and p ≥0.05, suggesting that the null hypothesis cannot be rejected and that the residuals are normally distributed. The Breusch-Godfrey LM test results indicate the absence of autocorrelation (LM = 0.8805, p ≥0.05), suggesting that the model residuals are independent and do not exhibit autocorrelation. Furthermore, the Breusch-Pagan-Godfrey (F = 1.1869, p ≥0.05) and ARCH (F = 0.1043, p ≥0.05) tests substantiate the conclusion that the residuals possess constant variance, signifying the absence of heteroskedasticity in the model. The Ramsey RESET test (F = 1.1731, p ≥0.05) indicates that the functional form of the model is correctly specified and that no significant variables have been omitted from the model.

The results of the NARDL model's error correction mechanism and short-term dynamics reveal the speed at which agricultural employment converges to long-term equilibrium and its short-term responses to various shocks (Table 7). The error correction term (LN_TIST (-1)), a critical component of the model, was estimated at -0.8893 and was found to be statistically significant (p ≤0.01). The negative and significant nature of this coefficient confirms the existence of the long-term relationship previously identified through the cointegration test, while the magnitude of the coefficient indicates that approximately 88.9% of the deviations from the previous period are corrected in the current period, suggesting that employment is rapidly approaching its long-term equilibrium level.

At this stage, only three of the variables that constitute the long-term relationship were found to be statistically significant: the lagged value of positive shocks in real producer support estimate (p ≤0.05), the lagged value of positive shocks in real agricultural credit (p≤0.10), and the lagged value of negative shocks in share of agriculture in GDP (p ≤0.05). The directions and magnitudes of these variables have been thoroughly examined within the framework of previously normalized long-run elasticity estimates (Table 6).

In the short run, negative changes in real agricultural product exports (D(LN_RIHR_TAR_NEG)) have had a statistically significant and negative impact of 5% on agricultural employment in the current period (Coefficient

= -0.7720, p≤0.05). In contrast, no significant effect of positive changes in exports (D(LN_RIHR_TAR_POS)) on agricultural employment was detected in the short term. A review of the extant literature reveals a variety of findings indicating that the relationship between agricultural exports and agricultural employment may be complex and asymmetric in terms of both direction and temporal effects. Khan et al. (2020) demonstrated in their study of the Pakistan agricultural sector that a two-way relationship exists between agricultural exports and agricultural employment in the short term. Furthermore, they showed that changes in exports may also affect employment. In a similar vein, Aytekin's (2024) analysis of Türkiye's economic landscape revealed that while employment growth in the agricultural sector initially led to an uptick in exports, this positive correlation eventually dissipated over time. These findings suggest that the relationship between employment and exports may be subject to variation depending on the time dimension and direction. Within this framework, the findings of the current study can be interpreted as consistent with the general trend in the literature, reflecting the short-term sensitivity of labor dynamics to trade shocks. This phenomenon suggests that export increases do not have a substantial impact on employment in the short term. This is likely that these increases are absorbed by existing capacity or their effect on employment manifests over time. Conversely, export declines have a more direct and rapid negative effect on employment.

Table 7. NARDL error correction model

Variable	Coefficient	Std. Error	t-statistic	Probability
C	7.7663	1.6119	4.8180	0.0005
Error Correction Term and Long Run Interactions				
LN_TIST (-1)	-0.8893***	0.1793	-4.9593	0.0004
LN_RPSE_POS (-1)	0.3520**	0.1369	2.5708	0.0260
LN_RPSE_NEG (-1)	-0.0325	0.1643	-0.1977	0.8469
LN_RIHR_TAR_POS (-1)	-0.8916	0.5575	-1.5992	0.1381
LN_RIHR_TAR_NEG (-1)	-0.5760	0.3823	-1.5067	0.1601
LN_RITH_TAR_POS	-0.0067	0.1370	-0.0491	0.9618
LN_RITH_TAR_NEG	-0.1472	0.1484	-0.9919	0.3426
LN_RTK_POS (-1)	0.3528*	0.1618	2.1808	0.0518
LN_RTK_NEG	-0.0035	0.1133	-0.0305	0.9762
TGSYHP_POS (-1)	-0.0343	0.0852	-0.4027	0.6949
TGSYHP_NEG (-1)	0.0939**	0.0388	2.4174	0.0342
Short Run Dynamics				
D(LN_RPSE_POS)	0.0440	0.1037	0.4244	0.6795
D(LN_RPSE_NEG)	0.0014	0.1209	0.0114	0.9911
D (LN_RPSE_NEG (-1))	-0.1777	0.1426	-1.2458	0.2387
D(LN_RIHR_TAR_POS)	-0.0615	0.2355	-0.2612	0.7988
D (LN_RIHR_TAR_POS (-1))	0.3925	0.2663	1.4739	0.1685
D(LN_RIHR_TAR_NEG)	-0.7720**	0.3447	-2.2395	0.0467
D (LN_RIHR_TAR_NEG (-1))	-0.2584	0.1730	-1.4941	0.1633
D(LN_RTK_POS)	0.0008	0.1412	0.0054	0.9958
D (LN_RTK_POS (-1))	-0.2844*	0.1333	-2.1331	0.0563
D(TGSYHP_POS)	0.0303	0.0510	0.5938	0.5646
D (TGSYHP_POS (-1))	0.0967**	0.0357	2.7084	0.0203
D(TGSYHP_NEG)	0.0088	0.0261	0.3361	0.7431
Short Run Wald Test Results				
W_{SRLN_RPSE}: 1.7318 (0.2093)			$W_{SRTGSYHP}$: 3.8211(0.0709) *	
$W_{SRLN_RIHR_TAR}$: 11.0019(0.0051) ***				

, **, * indicate 1%, 5% and 10% significance level respectively*

The lagged value of positive changes in real agricultural credit (D (LN_RTK_POS (-1))), when considered in the context of agricultural employment, exhibits a significant negative effect in the short term (Coefficient = -0.2844, p ≤0.10). This suggests that increases in credits, despite their long-term employment-enhancing effect, may potentially lead to a reduction in agricultural employment in the short term. The extant literature contains various findings indicating that the short- and long-term effects of agricultural credit may differ and, in particular, may produce unexpected results in the short term. Gezer and Gezer (2022), posit that increases in agricultural credit have the potential to stimulate production in the short term. However, they contend that the delayed

effects of such measures can potentially have adverse consequences for production. In their analysis of the Nigerian agricultural sector, Saka et al. (2023) emphasized that short-term agricultural loans provided through banking institutions have significant and negative effects on agricultural development. In a similar vein, Gebeyehu and Bedemo's (2024) study revealed that agricultural loans exerted a deleterious effect on productivity in the short term in Ethiopia. The findings of these studies, which are oriented towards production and productivity, demonstrate that the adverse effects observed in agricultural production in the short term possess the capacity to diminish the demand for labor, which constitutes an input in the production process. Consequently, it is anticipated that the adverse repercussions of credit augmentation on production, which materialize with a temporal lag, will be manifest in agricultural employment in a congruent manner. This negative short-term effect can be explained by the fact that increased credit is primarily directed toward labor-saving technological investments or mechanization. While such investments may have a positive impact on employment in the long term through increases in production and productivity, they may initially reduce the existing labor demand. Moreover, the restructuring of farms that are financed by credit can result in short-term labor shortages. In this context, the current findings are consistent with trends documented in the extant literature and point to the dynamic and asymmetric nature of the agricultural finance-labor interaction.

The positive change in share of agriculture in GDP (D (TGSYHP_POS (-1))), has a significant and positive short-term effect on agricultural employment (Coefficient = 0.0967, $p \leq 0.05$). This finding indicates that an increase in the agricultural share in the previous period increases current-period employment by approximately 10.15% ($100x(e^{0.0967}-1)$). This short-term positive effect is consistent with established knowledge in the literature on agricultural economics and development. This short-term positive effect demonstrates that an increase in the contribution of the agricultural sector to the economy can create a temporary revival in agricultural activities and, consequently, in employment. This phenomenon can be partially attributed to the cyclical and seasonal nature of agricultural production. Favorable conditions or increased investments in one period can trigger higher labor demand for activities such as harvesting, processing, or marketing in the subsequent period (Kulikova et al., 2021; Olakojo & Sheet, 2016). Furthermore, particularly in developing economies, the agricultural sector can function as a "buffer" for employment during periods of economic downturns or structural transformation processes. In the event of a decline in employment opportunities in other sectors, individuals may opt to return to rural areas or engage in agricultural activities to sustain their livelihoods. An increase in the share of agricultural GDP can enhance the capacity to absorb this additional labor force (Timmer, 1997).

The results of the Wald test for the short-term symmetry analysis of the NARDL model reveal that certain variables exhibit asymmetric effects on agricultural employment in the short term (Table 7). A statistically significant difference was identified between the short-term cumulative effects of positive and negative shocks in real agricultural product exports (Wald statistic = 11.0019, $p \leq 0.01$). This finding suggests that fluctuations in exports, characterized by increases and decreases, exert asymmetric short-term effects on agricultural employment. The effects of positive and negative shocks on the share of agriculture in GDP are statistically significant and asymmetric (Wald = 3.8211, $p \leq 0.10$). This suggests that changes in the TGSYHP variable may lead to varied short-term responses in agricultural employment. However, the short-term Wald test for the real producer support estimate indicates that the effects of positive and negative shocks are symmetrical (Wald = 1.7318, $p \geq 0.05$). Consequently, no substantial directional discrepancy is evident in the short term for this variable.

The structural stability of the NARDL model was evaluated using the CUSUM and CUSUMSQ tests developed by Brown et al. (1975) (Figure 3). The purpose of these tests is to determine whether the model parameters remain constant over time during the estimation period. In the context of the CUSUM test, the stability of the model's coefficients over time is determined by the maintenance of the cumulative sum of the recursive residuals within the critical limits established at a 5% significance level. On the other hand, the CUSUMSQ test is designed to identify potential structural breaks in the variance of the residuals and imbalances in variability.

The CUSUM and CUSUMSQ graphs show that the test statistics remained within the limits at the 5% level. This finding suggests that the parameters of the estimated NARDL model remained structurally consistent throughout the period and that the model estimates are reliable.

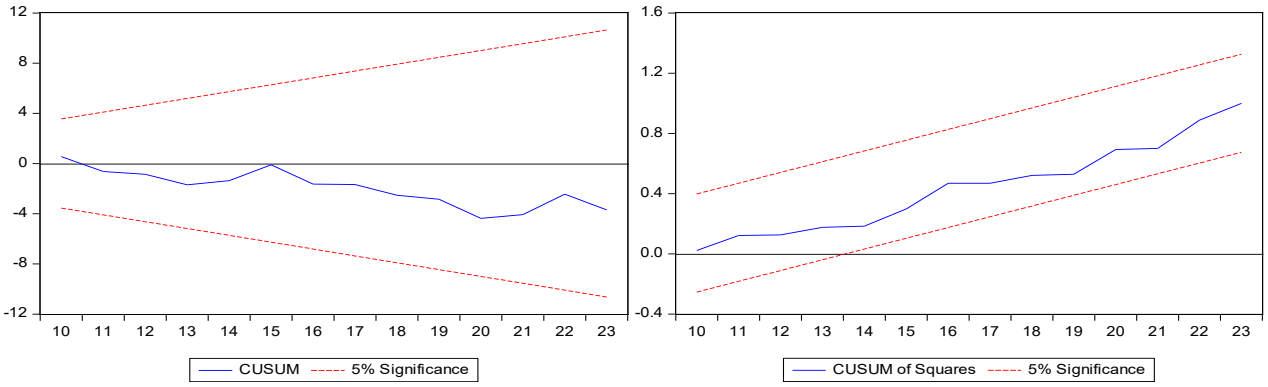

Figure 3. Evaluation of parameter stability with CUSUM and CUSUM-SQ tests

CONCLUSION

The present study examines the intricate nature of agricultural employment dynamics in Türkiye, with a particular focus on the asymmetric effects of macroeconomic and sectoral factors. The analysis utilizes the NARDL cointegration methodology to examine the impact of the OECD PSE index. The primary objective of this study is to reveal the short-term and long-term nonlinear effects of these critical variables on agricultural employment. The analyses underscore the limitations of conventional approaches predicated on the assumption of symmetric effects, illuminating the intricacies of responses to policy shocks and offering substantial methodological and empirical contributions to the extant literature.

The findings indicate that agricultural employment exhibits asymmetric responses to each determinant over different time horizons. Positive shocks in producer support estimates have been shown to have a significant and encouraging effect on agricultural employment in the long term. Additionally, the absence of such support does not produce the same symmetric negative effect. Similarly, increases in agricultural credit have been shown to have a positive effect on employment over the long term. However, these increases may result in a temporary decline in employment in the short term through labor-saving investments. These asymmetric responses necessitate flexibility and foresight in the design of support and credit policies.

Foreign trade dynamics have complex effects on agricultural employment. While an increase in agricultural exports has been shown to result in a reduction in employment over time, this phenomenon can be attributed to the structural transformation and increased capital intensity within the sector. This signifies a shift towards production methods that utilize more machinery and technology relative to human labor, thereby decreasing the overall demand for agricultural workers. In the short term, sudden declines in exports have a direct and negative impact on employment, revealing the sector's vulnerability to external shocks. In contrast, the decline in the share of agriculture in GDP, particularly during periods of economic fragility, has demonstrated that the sector functions as a critical "employment buffer" by increasing agricultural employment in the long term. In the short term, increases in the agricultural share have been shown to have a positive effect on employment, thereby demonstrating the sector's capacity for recovery.

These analyses underscore the intricate equilibrium exhibited by the policies implemented in Türkiye's agricultural sector, which is contingent upon the direction, magnitude, and timing of their repercussions on labor dynamics. The model's robust error correction mechanism demonstrates that employment quickly converges toward its long-term equilibrium. However, asymmetric responses in the short term highlight the necessity of proactive and adaptive policy interventions in response to sudden shocks. In this context, the following strategic approaches can be considered:

- Development of Flexible Support and Credit Mechanisms: Policies designed to support and encourage employment in the agricultural sector can be developed with consideration for their potential asymmetric effects. To bolster the sector against adverse economic shocks, it is recommended that diversified and flexible credit and support packages be developed. In order to mitigate the short-term potential negative effects, it would be beneficial to direct credits toward labor-intensive sub-sectors and rural diversification projects (e.g., skill development programs, microfinance).
- Integration of Employment-Focused Trade Policies: It is imperative to align agricultural export strategies with employment targets. Incentives can be directed towards products and value chains that utilize a greater proportion of local inputs and are characterized by high labor intensity. In order to address the issue of potential labor displacement resulting from foreign trade, there is a need to implement policies

that focus on the creation of non-agricultural employment opportunities in rural areas and the facilitation of labor transitions. Examples of such policies include vocational training programs and initiatives to support local entrepreneurship. Furthermore, the enhancement of risk management instruments, such as market diversification and export insurance, has the potential to bolster the resilience of specific sectors against external shocks.

- Strategic Optimization of Agriculture's "Buffer" Role: The role of agriculture as an employment buffer during periods of economic fluctuation necessitates the formulation of policies aimed at enhancing the productivity and quality of the workforce in this sector. Investments in rural infrastructure, facilitating market access for small-scale farmers, and expanding social safety nets to include the agricultural sector can be supported. The ultimate objective may be for the agricultural sector to transition from a state of mere "reserve" to one that provides more stable and high-productivity employment opportunities for the overall economy in the long term.
- Frameworks for the Evaluation of Adaptive and Data-Driven Policy: In policy impact analyses and future projections, it is imperative to employ advanced econometric modeling techniques that internalize the asymmetric and dynamic relationships revealed in this study. This approach has the potential to maximize policy effectiveness and minimize possible undesirable outcomes.

Limitations: While this study provides significant findings on the asymmetric effects of agricultural policy support on employment, several methodological and data-related limitations must be acknowledged. Firstly, given that the analysis is predicated on annual time series data, short-term fluctuations and seasonal dynamics specific to the agricultural labor market may not be adequately captured by the model. Secondly, while the NARDL approach offers advantages in modeling nonlinear and asymmetric relationships, it is constrained by a fundamental limitation: it cannot accommodate variables that are integrated of order two (I(2)). Furthermore, the model demonstrates limited sensitivity to structural breaks and may not flexibly account for time-varying policy regimes or shifts driven by external shocks. The complexity of the model, particularly in cases involving multiple lags or explanatory variables, can result in interpretative challenges and necessitate caution when working with small sample sizes.

Thirdly, the PSE indicator employed in the analysis reflects solely the quantitative magnitude of support, disregarding qualitative aspects such as targeting efficiency, policy design, and the directional focus of interventions. Consequently, the explanatory power of the model may be limited in cases where structural changes in policy composition occur without a corresponding change in the overall PSE value. Additionally, the utilization of nationally aggregated data for both PSE and agricultural credit may obfuscate regional disparities and sector-specific effects.

In light of these limitations, future research could benefit from the incorporation of higher-frequency data (e.g., quarterly or monthly time series) to more effectively capture seasonal and short-run dynamics within the agricultural labor market. In addition, the integration of empirical findings with micro-level qualitative data, such as farm household surveys, has the potential to offer more profound insights into the behavioral impacts of policy support on employment decisions.

Declaration of interests

The Author declares that there is no conflict of interest

Author Contributions

Zekiye Şengül Abedı contributed to the study by conceptualizing the research, designing the methodology, conducting data collection and analysis, and preparing the manuscript.

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Original Article

The Effects of Hot and Cold Infusions on Some Quality Characteristics and Bioactivity of Walnut (*Juglans regia* L.) Leaf Tea Enriched with Different Spices

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ABSTRACT

Walnut leaves are an important agricultural by-product rich in bioactive compounds. This study investigated the effects of infusion conditions (hot and cold) on total phenolic content (TPC), total flavonoid content (TFC), total antioxidant activity (DPPH• radical scavenging capacity, CUPRAC, and FRAP), pH, color and sensory characteristics of walnut (*Juglans regia* L.) leaf tea (WLT) infusions enriched with cinnamon, clove and cardamom. The addition of spices significantly affected the pH values, color parameters and bioactivity of the WLT infusions (p<0.01). The pH value decreased in all infusions with the addition of spices (5.72-5.35), while the *L** value (49.48-51.07) increased. The addition of clove dramatically increased *b**, *H°*, and *C** values, whereas cardamom decreased these values compared to the control tea infusions. The TPC, TFC, DPPH• radical scavenging capacity, CUPRAC and FRAP of the WLT infusions ranged from 181.49 to 286.71 mg GAE/L, 440.21 to 531.46 mg QE/L, 228.84 to 339.63 mg TE/L, 676.25 to 1233.33 mg TE/L and 171.96 to 435.91 mg TE/L, respectively. The difference between the hot and cold infusions was found to be significant (p<0.05) in TPC, CUPRAC, *b**, *H°*, and *C** values. With both infusion methods, the highest antioxidant activity was detected in WLT infusions enriched with clove, whereas the lowest was detected in WLT infusions enriched with green cardamom. Principal component analysis (PCA) demonstrated that clove dramatically affected the antioxidant activity of WLT infusions. Generally, it was determined that the addition of spices improved the sensory characteristics of WLT infusions and increased consumer appreciation. Based on the total sensory score, the hot WLT infusions were appreciated in the following order: clove (40.53) > cardamom (39.13) > cinnamon (37.35) > control (37.08). Conclusively, walnut leaf and spices could be utilized in the production of a composite herbal tea with good quality and sensory attributes for human consumption.

Key words: Herbal tea, walnut leaves, spices, infusion, bioactive compounds, antioxidant activity

Farklı Baharatlarla Zenginleştirilmiş Ceviz (*Juglans regia* L.) Yaprağı Çayının Bazı Kalite Özellikleri ve Biyoaktivitesi Üzerine Sıcak ve Soğuk İnfüzyonun Etkileri

ÖZ

Ceviz yaprakları biyoaktif bileşiklerce zengin önemli bir tarımsal yan üründür. Bu çalışmada, tarçın, karanfil ve kakule ile zenginleştirilmiş ceviz (*Juglans regia* L.) yaprağı çay (WLT) infüzyonlarının toplam fenolik içeriği (TPC), toplam flavonoid içeriği (TFC), toplam antioksidan aktivitesi (DPPH• radikal süpürme kapasitesi, CUPRAC ve FRAP), pH, renk ve duyusal özellikleri üzerine infüzyon koşullarının (sıcak ve soğuk) etkileri araştırılmıştır. Baharat ilavesi, WLT infüzyonlarının pH değerlerini, renk parametrelerini ve biyoaktivitesini önemli ölçüde etkilemiştir (p<0.01). Baharat ilavesiyle tüm infüzyonlarda pH değeri azalırken (5.72-5.35), *L** değeri (49.48-51.07) artmıştır. Karanfil ilavesi *b**, *H°* ve *C** değerlerini önemli ölçüde artırırken, kakule bu değerleri kontrol çay infüzyonlarına kıyasla azaltmıştır. WLT infüzyonlarının TPC, TFC, DPPH• radikal süpürme kapasitesi, CUPRAC ve FRAP değerleri sırasıyla 181.49-286.71 mg GAE/L, 440.21-531.46 mg QE/L, 228.84-339.63 mg TE/L, 676.25-1233.33 mg TE/L ve 171.96-435.91 mg TE/L aralığında değişmiştir. TPC, CUPRAC, *b**, *H°* ve *C** değerleri bakımından sıcak ve soğuk

infüzyonlar arasındaki fark önemli bulunmuştur (p<0.05). Her iki infüzyon yönteminde de en yüksek antioksidan aktivite karanfil ile zenginleştirilmiş WLT infüzyonlarında tespit edilirken, en düşük kapasite yeşil kakule ile zenginleştirilmiş WLT infüzyonlarında tespit edilmiştir. Temel bileşen analizi (PCA), karanfilin WLT infüzyonlarının antioksidan aktivitesini önemli ölçüde etkilediğini göstermiştir. Genel olarak, baharat ilavesinin WLT infüzyonlarının duyusal özelliklerini iyileştirdiği ve tüketici beğenisini artırdığı tespit edilmiştir. Sıcak WLT infüzyonlarının toplam duyusal puan açısından beğeni sıralaması karanfil (40.53) > kakule (39.13) > tarçın (37.35) > kontrol (37.08) şeklindedir. Sonuç olarak, ceviz yaprağı ve baharatlar, insan tüketimi için iyi kalite ve duyusal özelliklere sahip kompozit bir bitki çayı üretiminde kullanılabilir.

Anahtar kelimeler: Bitki çayı, ceviz yaprağı, baharatlar, infüzyon, biyoaktif bileşikler, antioksidan aktivite

INTRODUCTION

Tea obtained from young shoots of *Camellia sinensis* is the most consumed beverage in the world after water (Chan et al., 2010; Winiarska-Mieczan and Baranowska-Wójcik, 2024). Recently, herbal teas, also known as herbal infusions, have become increasingly popular among consumers as caffeine-free sources of hydration rich in natural antioxidant compounds (Newman et al., 2023). Herbal teas are recognized as functional foods that have health benefits and attract the attention of consumers due to the bioactive compounds they contain (polyphenols, flavonoids, terpenoids, volatile oils, alkaloids, organic acids, etc.) (Liu et al., 2023; Joshua et al., 2023). Growing demand for functional beverages among health-conscious consumers is predicted to drive a 6% growth in the herbal tea market from 2021 to 2028 (Newman et al., 2023). Medicinal plants are mostly used as raw materials for preparing herbal tea infusions. Herbal teas are brewed from the roots, stems, leaves, fruits, flowers, seeds, bark, or whole parts of one or more plant species (dried or fresh) (Liu et al., 2023). The potential health benefits of herbal teas are associated with their nutrient and phytochemical content after brewing. Therefore, it is important to study different brewing methods for herbal tea preparation (Newman et al., 2023; Winiarska-Mieczan and Baranowska-Wójcik, 2024). The most practical and commonly used traditional practice is the preparation of teas by infusion or decoction (Büyükbalci and El, 2008). In the hot herbal tea brewing method, herbs are brewed in boiling water for 5 min, while in the increasingly popular cold brewing method, herbs are generally brewed in room temperature water for 2 hours (Newman et al., 2023).

Medicinal and aromatic plants have been used for centuries for their health-promoting properties due to the phytochemical compounds they contain. Recently, as stated by the World Health Organization (WHO), medicinal plants are widely used by consumers due to their therapeutic and nutritional properties, thus increasing expenditures on medicinal plant products (Thakur and Kumar, 2021; Salık and Çakmakçı, 2021). These plants are generally included in forest trees, ornamental plants, spices and condiments (Gahukar et al., 2018). The medicinal properties of a plant can be attributed to the primary and secondary components found in different parts (leaves, roots, stem, bark, fruits, seeds and flowers) of the plant (Islam et al., 2020; Salık and Çakmakçı, 2021).

Walnut leaf, which is a medicinal and aromatic plant, is an important source used in folk medicine for the treatment of various diseases, and its phytochemical profiles have been determined in studies (Salık and Çakmakçı, 2023). Walnut leaves are collected from the walnut tree of the *Juglandaceae* family (Jahanban-Esfahlan et al., 2019). Walnut leaves are a valuable agricultural by-product that is cheap and abundant (Salık, 2023). Walnut leaf has health and medication properties as a plant-based product because it contains bioactive compounds such as phenolic acids, flavonoids, organic acids, tocopherols, triterpenic acids, terpenes, terpenoids, tetralone derivatives, megastigman derivatives, and 5-hydroxy-1,4-naphthoquinone (juglon) and volatile flavor compounds (predominantly caryophyllene oxide, β-caryophyllene, germacrene, α-pinene, and β-pinene) (Vieira et al., 2019; Salık and Çakmakçı, 2023). In addition, walnut leaves are rich in protein, fat, carbohydrate, and minerals (Salık, 2023). Walnut leaves are widely used in folk medicine to treat venous insufficiency, hemorrhoids, hypoglycemia, diarrhea, and fungal or microbial infections (Bou Abdallah et al., 2016). Numerous *in vitro* and *in vivo* epidemiological studies have been conducted to determine the therapeutic properties of walnut leaves. These studies have revealed that walnut leaves are beneficial for human health with many properties such as antioxidant, antimicrobial, antifungal, anti-inflammatory, antidiabetic, antihelminthic, antidiarrheal, antihistamine, antiulcer, antiasthmatic, immunomodulatory, antifertility, and hepatoprotective (Jahanban-Esfahlan et al., 2019; Vieira et al., 2019). Moreover, walnut leaves with their rich bioactive and chemical compound profile have the potential to be used in the development of high-value-added products and functional foods (Salık and Çakmakçı, 2023; Salık, 2023).

Spices are important gastronomic ingredients that have been used since ancient times to enhance the flavor of foods (meat, bread, dairy products, beverages, etc.), improve their organoleptic properties and extend

the shelf life of foods, in addition to their medicinal uses (Muzolf-Panek and Stuper-Szablewska, 2021). Additionally, spices (cinnamon, cloves, etc.) have been reported to have the potential to be used as natural antioxidants and antibacterial agents in the production of edible films as packaging materials (Bulut and Ertaş, 2024). In this study, clove (*Syzygium aromaticum* L.) flower buds, cinnamon (*Cinnamomum verum* L.) bark, and whole green cardamom (*Elettaria cardamomum* L.) pods were selected from medicinal-aromatic spices to improve the sensory properties of walnut leaf tea (WLT) infusions and facilitate tea drinkability by consumers.

Walnut leaves are known to be used as infusions in rural areas and folk medicine practices. Additionally, numerous studies have shown the phytochemical and nutraceutical benefits of walnut leaves. However, to the best of my knowledge, this is the first comparative study focused on the effects of different spices (cinnamon, clove and cardamom) enrichment and infusion methods (hot and cold) on the bioactivity (TPC, TFC, DPPH• radical scavenging capacity, CUPRAC, and FRAP), physicochemical (pH and color) and sensory characteristics of walnut leaf tea (WLT). It was hypothesized that both infusion method and spice enrichment would significantly influence these quality parameters, with hot infusion and clove enrichment expected to provide superior antioxidant and sensory attributes. Thus, the results of this research contribute to the creation of a new alternative use for walnut leaves, a valuable agricultural waste.

MATERIALS AND METHODS

Materials

Walnut leaves were collected from walnut trees (*Juglans regia* L.) belonging to a local genotype (Şebin) from a garden in Erzincan Province (Turkey), washed, and dried (5–6 days) in the shade. Then, the dried walnut leaves (95% dry matter) were ground using a laboratory blender (Blender 8011ES, HGB2 WTS3 Model, USA) and passed through a sieve (2 mm) (Figure 1a). Cinnamon bark powder, clove flower buds and whole green cardamom pods were commercially purchased from the local spice bazaar at Bingöl, Turkey (Figure 1b-d, respectively). Clove buds and whole green cardamom pods samples were ground to a powder using a laboratory blender.

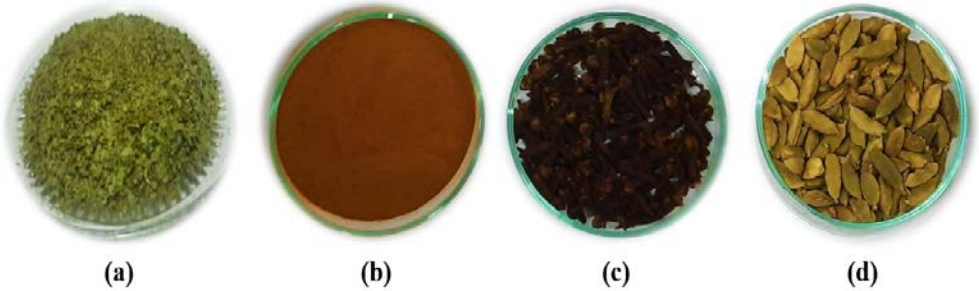


Figure 1. Walnut leaves (a) and spice samples (b: cinnamon bark powder, c: clove flower buds, d: whole green cardamom pods) used for the preparation of tea infusions

Preparation of herbal tea bags

A total of 4 tea formulations were prepared with dried walnut leaves, cinnamon, cloves, and cardamom (Table 1). To create a homogenized product for each brewing, spices (cinnamon, clove and green cardamom) and walnut leaf powder were mixed separately in a tea bag 20% (w/w) to produce a total of one grams. These tea bags were prepared in two replicates and used for all analyses. The infusion and preparation conditions used in this study are given in Table 1.

Table 1. The conditions of infusion and preparation of walnut leaf tea (WLT) enriched with different spices

Infusions	Tea samples	Tea formulations	Conditions
Cold or hot	Control	1 g of ground walnut leaf + 200 mL of purified water (25 °C or 90 °C)	2 hours at room temperature (cold) or 7 min at 90 °C (hot)
	Cinnamon	1 g of tea mix (0.8 g walnut leaf + 0.2 g cinnamon) + 200 mL purified water (25 °C or 90 °C)	
	Clove	1 g of tea mix (0.8 g walnut leaf + 0.2 g clove) + 200 mL purified water (25 °C or 90 °C)	
	Cardamom	1 g of tea mix (0.8 g walnut leaf + 0.2 g cardamom) + 200 mL purified water (25 °C or 90 °C)	

Preparation of tea infusions

Cold infusions

Cold infusions of WLT samples were carried out according to the method suggested by Dasdemir et al. (2023), with some modifications. Briefly, 1 g of tea sample was treated with 200 mL of pure water at 25 °C. The mixture was shaken in an orbital shaker (IKA KS 130, IKA) set at 400 rpm for 2 h under dark conditions and at room temperature. The infusions were then filtered through Whatman No. 1 filter papers and stored at –20 °C until analyzed.

Hot infusions

Hot infusions of WLT samples were carried out according to the method suggested by Dasdemir et al. (2023), with some modifications. Briefly, 1 g of tea sample was added to 200 mL of boiling water (90 °C) and left to infuse for 7 min in a hot water bath. The infusions were then filtered through Whatman No. 1 filter papers and stored at –20 °C until analyzed.

Preparation of extracts from plant materials for bioactivity analyses

Plant extracts were prepared according to the method proposed by Salık (2023), with slight modifications. 0.5 g of the sample was mixed with 25 mL of ethanol-water solution (80:20, v/v). The mixture was shaken in an orbital shaker (IKA KS 130, IKA) set at 400 rpm for 24 h under dark conditions and at room temperature. The samples were then centrifuged (Hettich Zentrifugen Universal 32R, UK) at 10000 rpm for 10 min at 25 °C. The supernatants were filtered through Whatman No. 1 filter papers, and the extracts were stored at –20 °C until analyzed. The prepared extracts were analyzed for TPC, TFC and total antioxidant activity (DPPH•, CUPRAC and FRAP assays).

pH and color measurement

The pH values of the WLT infusions and plant materials were measured using a digital pH meter (Seven Compact TM pH/Ion S220 brand) at room temperature. To measure the pH of the plant materials, 1 g of sample was homogenized with 10 mL of distilled water. The color parameters of the tea infusions and plant materials were recorded by colorimetry (Minolta CR-200, Minolta Chromometer, Japan) as L^* (100: white, 0: black), a^* (+: red, -: green), b^* (+: yellow, -: blue), $H°$ (hue angle; 0°: red, 90°: yellow, 180°: green, 270°: blue, 360°: red) and C^* (color saturation). Color measurements were taken after the samples were transferred to a 10 cm petri plate (Rahimmalek et al., 2013).

Total phenolic content (TPC) of tea infusions

The TPC's of tea infusions and plant extracts were determined using the Folin-Ciocalteu method reported by Chan et al. (2009), with slight modifications. Samples (300 µL) were introduced into test tubes followed by 1.5 mL of freshly prepared Folin-Ciocalteu reagent (10%, v/v) and 1.2 mL of sodium carbonate (7.5%, w/v). After incubating for 90 min in the dark at room temperature, the absorbance was measured at 765 nm using UV–Vis spectrophotometer (T60 Visible Spectrophotometer, PG instrument, UK). The results were expressed as mg of gallic acid equivalents (GAE) per liter of infusions.

Total flavonoid content (TFC) of tea infusions

The TFC's of tea infusions and plant extracts were determined using the aluminum chloride method reported by Dewanto et al. (2002). Samples (250 µL) were introduced into test tubes followed by 75 µL of sodium nitrite (5%, w/v) and 1.25 mL of distilled water. After 6 min, 150 µL of aluminum chloride (10%, w/v) was added. After 5 min, 0.5 mL of sodium hydroxide (1 M) was added. The mixture was brought to 2.5 mL with distilled water and mixed for 10 seconds. The absorbance of the reaction mixture was measured at 510 nm. The results were expressed as mg of quercetin equivalent (QE) per liter of infusions.

Determination of the antioxidant activity of tea infusions

The 1,1-diphenyl-2-picrylhydrazyl (DPPH•) radical scavenging capacity, the cupric ion reducing antioxidant capacity (CUPRAC) and the ferric reducing antioxidant power (FRAP) assays were used to determine the total antioxidant activity of tea infusions and plant extracts. All experiments were performed in duplicate, and the results were expressed as mg trolox equivalent (TE) per liter of infusions.

DPPH• radical scavenging assay

The DPPH• radical scavenging method was carried out based on Brand-Williams et al. (1995), with slight modifications. In the assay, 100 µL of sample was mixed with 2 mL of 0.1 mM DPPH• solution freshly prepared

in methanol. After incubating for 30 min in the dark at room temperature, the absorbance of the mixture was measured against that of the blank at 517 nm.

CUPRAC assay

The CUPRAC method was carried out based on Apak et al. (2006). In the assay, 100 µL of sample was mixed with 1 mL of copper (II) chloride solution (10 mM), 1 mL of neocuproine solution (7.5 mM), 1 mL of ammonium acetate (1 M, pH 7), and 1 mL of distilled water. After 30 min of incubation, the absorbance of the mixture was against that of the blank at 450 nm.

FRAP assay

The FRAP method was carried out based on Benzie and Strain (1996). In the assay, 200 µL of sample was mixed with 1.8 mL of FRAP reagent [freshly prepared by mixing 300 mM acetate buffer (pH 3.6), 10 mM TPTZ solution and 20 mM ferric chloride hexahydrate at a ratio of 10:1:1 (v/v/v)]. After 4 min of incubation, the absorbance was measured against that of the blank at 593 nm.

Descriptive sensory analysis of tea infusions

The sensory analysis of WLT infusions was assessed using the nine-point hedonic test by a panel of 20 people (semi-educated; 15 females and 5 males; aged 20 to 30 years). The panelists, who consume tea daily, were selected from students at the Department of Food Processing Bingöl University and were informed about how to conduct sensory evaluations before the test. For the hot tea infusion, the teabags that were prepared as described in Table 1 were infused with 1 L of hot water (90 °C) for 7 min. The panelists were given 4 different tea samples (50 mL) in a tea cup and water for neutralization between samples. The samples were graded on a scale ranging from 1 (poor) to 9 (excellent) based on six sensory attributes: color, odor, flavor, astringence, foreign taste, and overall acceptability.

Statistical analyses

All data were analyzed via one-way ANOVA and Duncan's multiple comparison tests (p<0.05) via Statistical Package for Social Sciences (SPSS) Version 20.0 (SPSS Inc., Chicago, IL, USA) licensed software. Additionally, paired sample t-tests were used to evaluate whether there were any significant differences between the infusion methods. The correlation among the determined variables (color and bioactivity) was calculated with Pearson's correlation test (95% confidence interval). Correlation coefficients were categorized according to the classification proposed by Schober et al. (2018). Principal component analysis (PCA) was applied to correlate the data obtained from the experimental samples (raw plant materials and tea infusions) for bioactivity characteristics and pH (SIMCA-P + 14.1, UMETRICS).

RESULTS AND DISCUSSION

pH and color characteristics

The brewing conditions (quality, volume, and temperature of water, particle sizes of plant and brewing time) significantly affect the composition and quality of tea infusions (Nguyen and Chuyen, 2020; Zor et al., 2023). The pH values of plant materials and WLT infusions enriched with different spices are shown in Figure 2.

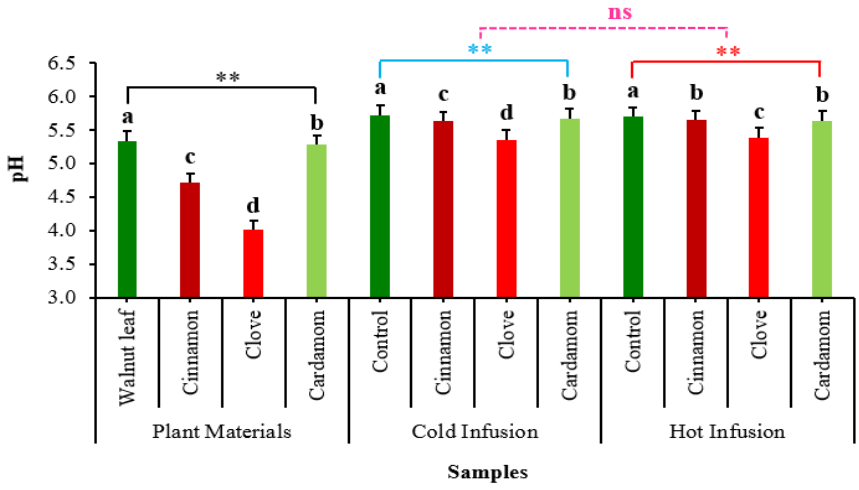


Figure 2. pH values of walnut leaf tea (WLT) infusions and plant materials (Different letters above the bars indicate significant differences, **: p<0.01; ns: no significant, p>0.05).

The addition of spices significantly (p<0.01) decreased the pH value of the tea infusions, whereas there was no difference between the infusion methods (p>0.05). The lowest pH value was determined in clove-enriched WLT infusions (5.35-5.39), whereas the highest pH value was detected in control WLT infusions (5.72-5.70). Similarly, Şengül et al. (2024) reported that the pH value varied between 5.20-6.28 in infused olive leaf tea samples and that infusion temperature (90 °C, 25 °C, 4 °C, and 0 °C) and particle size (whole and ground) affected pH. The pH relationship among tea infusions is similar to the relationship among plant materials (walnut leaf > cardamom > cinnamon > clove) (Figure 2).

Color is an important sensory characteristic of foods. The color values (L^*, a^*, b^*, $H°$, and C^*) of plant materials and WLT infusions enriched with different spices are given in Table 2. Accordingly, the color properties of the herbal materials used in the preparation of tea infusions were found to be specific and significantly different from each other (p<0.01). In walnut leaf, which constitutes the main ingredient (80%) of the formulated infusions, the L^* value was 48.50, a^* value -4.42, b^* value 18.83, $H°$ value 103.10, and C^* value 19.34. Comparable results were reported by Salık (2023) for walnut leaf powder. Among the spice samples, the highest L^*, a^*, b^*, and C^* values were detected in the cinnamon, whereas the lowest values (L^*, b^*, $H°$, and C^*) were determined in the clove (Table 2).

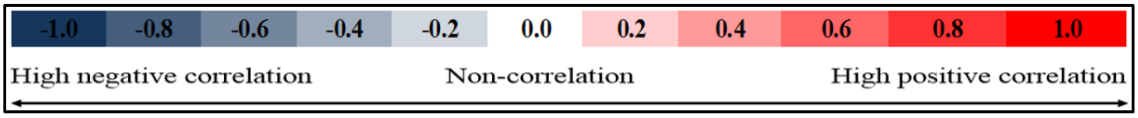
Table 2. Color parameters of walnut leaf tea (WLT) infusions and plant materials

Plant Materials	**n**	***L****	***a****	***b****	***H°***	***C****
Walnut leaf	3	48.50±0.13^{b}	-4.42±0.01^{d}	18.83±0.04^{b}	103.10±0.01^{a}	19.34±0.04^{b}
Cinnamon	3	54.54±0.59^{a}	16.35±0.15^{a}	24.00±0.51^{a}	29.04±0.33^{c}	29.04±0.33^{a}
Clove	3	23.60±1.30^{d}	4.11±0.76^{b}	1.54±0.30^{d}	20.50±0.14^{d}	4.38±0.81^{d}
Cardamom	3	44.54±1.97^{c}	1.75±0.59^{c}	15.10±2.39^{c}	83.55±1.20^{b}	15.20±2.44^{c}
p value		**	**	**	**	**
Tea Samples		***L****	***a****	***b****	***H°***	***C****
Control	8	49.48±0.49^{c}	2.05±0.03^{b}	7.31±0.18^{c}	74.38±0.58^{b}	7.59±0.17^{c}
Cinnamon	8	51.07±1.83^{a}	2.23±0.07^{a}	7.59±2.58^{b}	72.30±5.22^{c}	7.93±2.49^{b}
Clove	8	50.95±0.68^{a}	1.92±0.02^{c}	8.46±2.70^{a}	76.23±4.44^{a}	8.69±2.63^{a}
Cardamom	8	50.42±0.59^{b}	2.05±0.10^{b}	5.50±1.56^{d}	68.40±6.63^{d}	5.92±1.45^{d}
p value		**	**	**	**	**
Infusions		***L****	***a****	***b****	***H°***	***C****
Cold	16	50.80±1.49^{a}	2.08±0.11^{a}	5.64±1.33^{b}	69.05±5.24^{b}	6.03±1.23^{b}
Hot	16	50.16±0.95^{a}	2.05±0.18^{a}	8.79±1.95^{a}	76.61±2.72^{a}	9.05±1.89^{a}
p value		ns	ns	*	*	*

$^{a-d}$**:** Means with different letters in the same column are significantly different (***:** p<0.05, **ns:** no significant - p>0.05).

The addition of spices (p<0.01) and infusion methods (p<0.05) significantly affected the color parameters of WLT infusions. The L^* value indicates the brightness and is expressed as black (0) - white (100). In the tea infusions, the L^* values ranged from 49.48 to 51.07, the a^* values ranged from 1.92 to 2.23, the b^* values ranged from 5.50 to 8.46, *the* $H°$ values ranged from 68.40 to 76.23, and the C^* values ranged from 5.92 to 8.69 (Table 2). Similarly, Islam et al. (2020) reported that the L^* value was 50.82, 51.86 and 33.32, the a^* value was 0.25, -0.16 and 12.35, the b^* value was 4.82, 12.10 and 15.52 in tea infusions prepared from whole cardamom, cinnamon and clove, respectively. In another study, the L^* value of *Ginkgo biloba* leaf tea infusions was determined in the range of 32.10-34.47, a^* value 1.37-1.75, and b^* value 4.61-6.46 (Li et al., 2023). The addition of spices increased brightness in all infusions. When compared to the control group, the addition of cinnamon increased the a^* value, while the addition of cloves dramatically increased the b^*, $H°$ and C^* values. The addition of cardamom dramatically decreased b^*, $H°$ and C^* values. The b^* value was positively correlated (p<0.01) with the $H°$ (r= 0.93) and C^* (r = 1.00) values (Figure 3). The $H°$ values of all the tea infusions were between 0° and 90°, representing a color in the red–yellow region. As the color angle moves away from 0°, the color changes from red to yellow. The b^*, $H°$ and C^* values of hot infusions were higher than cold infusions. This may be because color substances pass more into the tea at high temperatures. Similarly, Zor et al. (2023) and Şengül et al. (2024) reported that the infusion temperature and time, and particle size significantly affected the color properties of *Clitoria ternatea* L. tea and olive leaf tea samples, respectively.

	*L**	*a**	*b**	*H°*	*C**	TPC	TFC	DPPH•	CUPRAC
a*	-0.057								
b*	-0.246	-0.110							
H°	-0.367	-0.325	0.929**						
C*	-0.240	-0.096	1.000**	0.922**					
TPC	-0.063	-0.540	0.715*	0.773*	0.706				
TFC	-0.405	-0.067	0.410	0.503	0.398	0.682			
DPPH•	-0.271	-0.341	0.660	0.746*	0.651	0.923**	0.786*		
CUPRAC	0.052	-0.541	0.632	0.668	0.623	0.987**	0.653	0.897**	
FRAP	0.102	-0.611	0.486	0.538	0.475	0.936**	0.603	0.833*	0.974**



*: $p < 0.05$, **: $p < 0.01$

Figure 3. Pearson's correlation coefficients between color parameters and bioactivity of walnut leaf tea (WLT) infusions

Bioactivity characteristics

Total phenolic and flavonoid contents

Phenolic compounds (phenolic acids, lignans, stilbenes, etc.) and flavonoids (flavones, flavonols, flavanones, flavanonols, etc.) are the most common as natural antioxidants found in plants (Assefa et al., 2018). These compounds have attracted great interest due to their importance in the food and pharmacology industries (Li et al., 2023). Herbal teas are very important in human diets due to their high content of phenols (Kılıç et al., 2017). The TPC and TFC of plant materials and WLT infusions enriched with different spices are given in Table 3. Accordingly, TPC of walnut leaf was 29.53 mg GAE/g, TFC 63.95 mg QE/g, DPPH• radical scavenging capacity 21.68 mg TE/g, CUPRAC 115.63 mg TE/g, and FRAP 22.35 mg TE/g. Similarly, Yapıcı and Kıvanç (2023) reported that the TPC was 28.63-75.00 mg GAE/g and the TFC was 11.44-54.99 mg QE/g in walnut leaves. In another study, the TPC, TFC, DPPH• radical scavenging capacity, CUPRAC, and FRAP of walnut leaf were reported as 48.30 mg GAE/g, 136.38 mg QE/g, 47.16 mg TE/g, 165.94 mg TE/g, and 48.61 mg TE/g, respectively (Salık, 2023).

The addition of spices significantly affected the phenolic and flavonoid contents of tea infusions (p<0.01). The lowest TPC (181.49 mg GAE/L) and TFC (440.21 mg QE/L) were detected in the WLT infusions enriched with cardamom, while the highest TPC (286.71 mg GAE/L) and TFC (631.46 mg QE/L) were detected in the WLT infusions enriched with clove. Similarly, Newman et al. (2023) determined that the TPC was in the range of 60-443 mg GAE/L and the TFC was in the range of 10.40-66.00 mg QE/L for lemon balm (*Melissa officinalis* L.) herbal tea samples. The researchers reported that the amount of phenolic compounds in herbal teas was significantly affected by harvest time (adult and microgreen) and brewing conditions (cold and hot) (Newman et al., 2023). Damiani et al. (2019) reported that the TPC in red (fermented) and green (unfermented) rooibos (*Aspalathus linearis*) herbal tea samples ranged from 265.4 to 692.4 mg GAE/L and 508.7 to 1019.0 mg GAE/L, depending on the brewing conditions, respectively. When compared to the control tea infusion, the addition of clove dramatically increased the total phenolic and flavonoid contents, whereas cardamom decreased them. This is consistent with the relationship among plant materials. Because the highest TPC and TFC were detected in cinnamon and clove samples compared to walnut leaf. Cardamom showed the lowest bioactivity (3.98 mg GAE/g for TPC and 9.64 mg QE/g for TFC) (Table 3). Previously, similar relationships for bioactivity were shown by Assefa et al. (2018) and Muzolf-Panek and Stuper-Szablewska (2021) as follows: clove > cinnamon > cardamom. Similarly, Kidon et al. (2023) reported that enrichment with dried chokeberry pomace increased the TPC of green tea and hibiscus flower infusions.

The TPC and TFC in the tea samples obtained via cold infusions were lower than those obtained via hot infusions. The difference between the infusion methods was found to be statistically significant in TPC (p<0.05), whereas it was not significant in TFC (p>0.05). Similarly, Dasdemir et al. (2023) reported that the TPC of hot infusions (108.13-304.80 mg GAE/g) was higher than that of cold infusions (92.80-271.47 mg GAE/g) in blueberry-added black tea samples. Kılıç et al. (2017) reported that TPC and TFC of *Camellia sinensis* (green tea), *Zea mays* (corn silk), *Cassia* sp. (senna), and *Rosmarinus officinalis* (rosemary) teas brewed at different water temperatures (60 °C, 80 °C, and 100 °C) increased with increasing temperature. The researchers found the highest TPC in senna tea and the highest TFC in rosemary tea (Kılıç et al., 2017). Damiani et al. (2019) obtained the highest TPC in Rooibos (*Aspalathus linearis*) herbal tea infusions with hot brewing methods. Researchers explained this by the

fact that increasing infusion temperature increases the diffusion of substances in contact with the solvent, facilitating the transfer of polyphenols to water (Cacace and Mazza, 2003; Zor et al., 2023).

Table 3. The TPC, TFC and antioxidant activity (DPPH•, CUPRAC, and FRAP) of walnut leaf tea (WLT) infusions and plant materials

Plant Materials	**n**	**TPC (mg GAE/g)**	**TFC (mg QE/g)**	**DPPH· (mg TE/g)**	**CUPRAC (mg TE/g)**	**FRAP (mg TE/g)**
Walnut leaf	3	29.53±0.59^{c}	63.95±0.63^{c}	21.68±0.13^{c}	115.63±0.59^{c}	22.35±0.35^{c}
Cinnamon	3	56.99±5.41^{b}	222.07±8.08^{b}	130.15±1.63^{b}	297.29±4.12^{b}	77.65±3.19^{b}
Clove	3	145.98±6.31^{a}	284.21±11.11^{a}	174.00±1.63^{a}	730.83±30.35^{a}	426.25±24.12^{a}
Cardamom	3	3.98±0.10^{d}	9.64±1.11^{d}	2.10±0.18^{d}	14.33±0.21^{d}	2.37±0.05^{d}
p value		**	**	**	**	**
Tea Samples		**TPC (mg GAE/L)**	**TFC (mg QE/L)**	**DPPH· (mg TE/L)**	**CUPRAC (mg TE/L)**	**FRAP (mg TE/L)**
Control	8	206.58±21.95^{b}	588.96±79.47^{ab}	251.77±20.62^{c}	755.83±110.06^{b}	203.08±24.67^{b}
Cinnamon	8	206.46±32.35^{b}	563.96±109.66^{b}	271.91±60.59^{b}	802.92±138.79^{b}	206.20±36.01^{b}
Clove	8	286.71±13.51^{a}	631.46±97.10^{a}	339.63±23.34^{a}	1233.33±121.05^{a}	435.91±22.00^{a}
Cardamom	8	181.49±30.15^{c}	440.21±47.42^{c}	228.84±49.51^{d}	676.25±107.89^{c}	171.96±24.81^{c}
p value		**	**	**	**	**
Infusions		**TPC (mg GAE/L)**	**TFC (mg QE/L)**	**DPPH· (mg TE/L)**	**CUPRAC (mg TE/L)**	**FRAP (mg TE/L)**
Cold	16	198.09±48.03^{b}	531.11±118.42^{a}	247.97±68.67^{a}	778.54±254.92^{b}	235.55±122.77^{a}
Hot	16	242.53±34.93^{a}	581.20±97.20^{a}	298.11±30.05^{a}	955.63±212.04^{a}	273.03±97.06^{a}
p value		*	ns	ns	*	ns

$^{a-d}$: Means with different letters in the same column are significantly different (***:** p<0.05, ******: p<0.01, **ns:** no significant - p>0.05).

Antioxidant activity

The results of antioxidant activity (DPPH•, CUPRAC, and FRAP) analysis of plant materials and WLT infusions enriched with different spices are given in Table 3. The addition of spices significantly affected the antioxidant activity of tea infusions (p<0.01). The lowest DPPH• (228.84 mg TE/L), CUPRAC (676.25 mg TE/L), and FRAP (171.96 mg TE/L) were detected in the WLT infusions enriched with cardamom, whereas the highest DPPH• (339.63 mg TE/L), CUPRAC (1233.33 mg TE/L), and FRAP (435.91 mg TE/L) were detected in the WLT infusions enriched with clove. A strong positive correlation was found between phenols and antioxidant activity (r= 0.92 for DPPH•, r= 0.99 for CUPRAC, and r= 0.94 for FRAP; p<0.01) in infused tea samples. When compared to the control tea infusion, the addition of clove and cinnamon dramatically increased the antioxidant activity, whereas cardamom decreased it. This finding is consistent with the antioxidant activity levels of the plant materials, which followed the order: clove > cinnamon > walnut leaf > cardamom (Table 3). Similar to the relationship among the bioactivity of spice samples, Islam et al. (2020) determined the highest bioactivity (TPC, TFC, $ABTS^{\bullet+}$, and DPPH• radical scavenging capacity) in tea infusions prepared from whole and ground spices (cardamom, cinnamon, cloves, black cumin and ginger) in clove tea infusion, whereas the lowest bioactivity was determined in cardamom tea infusion. Furthermore, researchers have reported increased bioactivity in herbal tea infusions with grinding of spices (Islam et al., 2020).

The antioxidant activity of the tea samples obtained via cold infusions was lower than those obtained via hot infusions. The difference between the infusion methods was found to be statistically significant in the CUPRAC assay (p<0.05), whereas it was not significant in the DPPH• and FRAP assays (p>0.05). Previous studies have reported that the highest antioxidant activity in some herbal tea infusions (rooibos, hibiscus calyces, blueberry-added black tea, and lemon balm) was obtained with hot brewing (Damiani et al., 2019; Paraíso et al., 2021; Dasdemir et al., 2023; Newman et al., 2023). Another study reported that antioxidant activity increased with increasing infusion temperature (70 °C, 80 °C, and 90 °C) and times (9, 18, and 27 min) for *Clitoria ternatea* L. tea (Zor et al., 2023). On the contrary, Şengül et al. (2024) reported that the highest antioxidant activity was found in olive leaf teas infused at room temperature, followed by refrigerator, hot, and ice infusion methods.

Sensory evaluation

Sensory quality criteria of tea can vary according to climate, season, horticultural practices, plant age, and production or preparation conditions, and are one of the most decisive features in consumer preference

(Dasdemir et al., 2023). The level of flavor release and volatile compounds into the tea by the brewing method affects the sensory quality of the herbal tea (Nguyen and Chuyen, 2020). Sensory evaluation was limited to hot infusions, as preliminary observations indicated that flavor and aroma were more readily perceived at elevated temperatures. Furthermore, hot teas are more commonly consumed directly after brewing in traditional settings, making them more suitable for hedonic testing under controlled conditions. However, future studies may also consider cold infusions, given their growing popularity among consumers.

Sensory scores of hot WLT infusions enriched with different spices are shown in Figure 4. The enrichment of spices to infused WLT significantly affected the scores for color (p<0.01), odor (p<0.05) and foreing taste (p<0.05), whereas there was no significant effect (p>0.05) on flavor, astringence and overall acceptability (Figure 4). The color scores of the tea samples ranged from 5.93 to 7.45, the odor score ranged from 5.90 to 7.25, the flavor score ranged from 5.85 to 6.45, the astringence score ranged from 5.13 to 6.68, the foreign taste score ranged from 6.17 to 7.65, and the overall acceptability score ranged from 6.10 to 6.68. In the scoring criteria, 9–8 points indicate that there is no foreign taste, and 7–6 points indicate that there is very little. Compared to the control tea, the addition of cinnamon and cloves increased the perception of foreign taste, whereas the addition of cardamom attenuated the foreign taste. The tea samples were ranked in terms of total sensory score as follows: clove (40.53) > cardamom (39.13) > cinnamon (37.35) > control (37.08). The results revealed that the addition of spices improved the organoleptic properties of WLT.

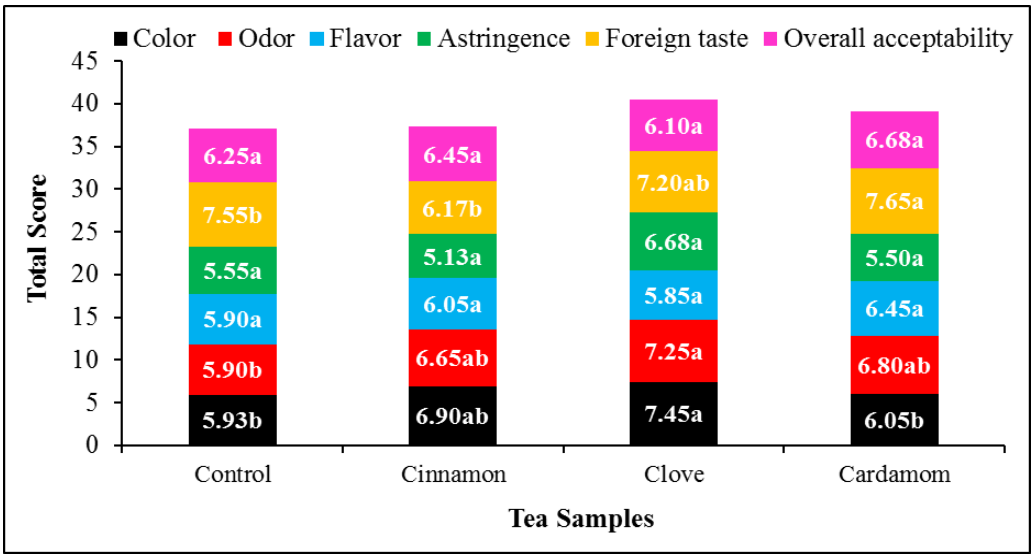


Figure 4. Sensory characteristics of walnut leaf tea (WLT) infusions (Means with different letters in the same color row are significantly different, p<0.05 or p<0.01)

Principal component analysis (PCA)

PCA analysis was performed on the six variables involved in the bioactivity characteristics (TPC, TFC, DPPH•, CUPRAC, and FRAP) and pH of the experimental samples (12 principal components). Figure 5 (a–d) shows the hierarchical clustering, score scatter plot, loading scatter plot, and biplot of the PCA for WLT infusions enriched with different spices. The first two principal components (PC) could explain 97.50% of the total variance. The PC1 was the most important, which explained 76.70% of the total variance. The PC2 explained 20.80 % of the variance. As a result of PCA, the experimental samples could be divided into four main groups (Figure 5a-b). In PC1, the cold and hot tea infusions are located on the right side of the axis, whereas the raw plant materials are located on the left side. In PC2, clove and cinnamon plant materials and clove-enriched tea infusion samples are located on the right side of the axis, whereas other plant materials and tea infusion samples are located on the left side (Figure 5b). Among the tea samples, the clove-added infusions were collected in dramatically different positions from the other infusions. Similarly, the clove sample is positioned differently from other plant materials. However, PCA did not reveal any difference between infusion methods. As shown in Figure 5c, positive correlations were observed between antioxidant properties. This classification revealed that the addition of clove dramatically affected the antioxidant activity of the WLT infusions (Figure 5d).

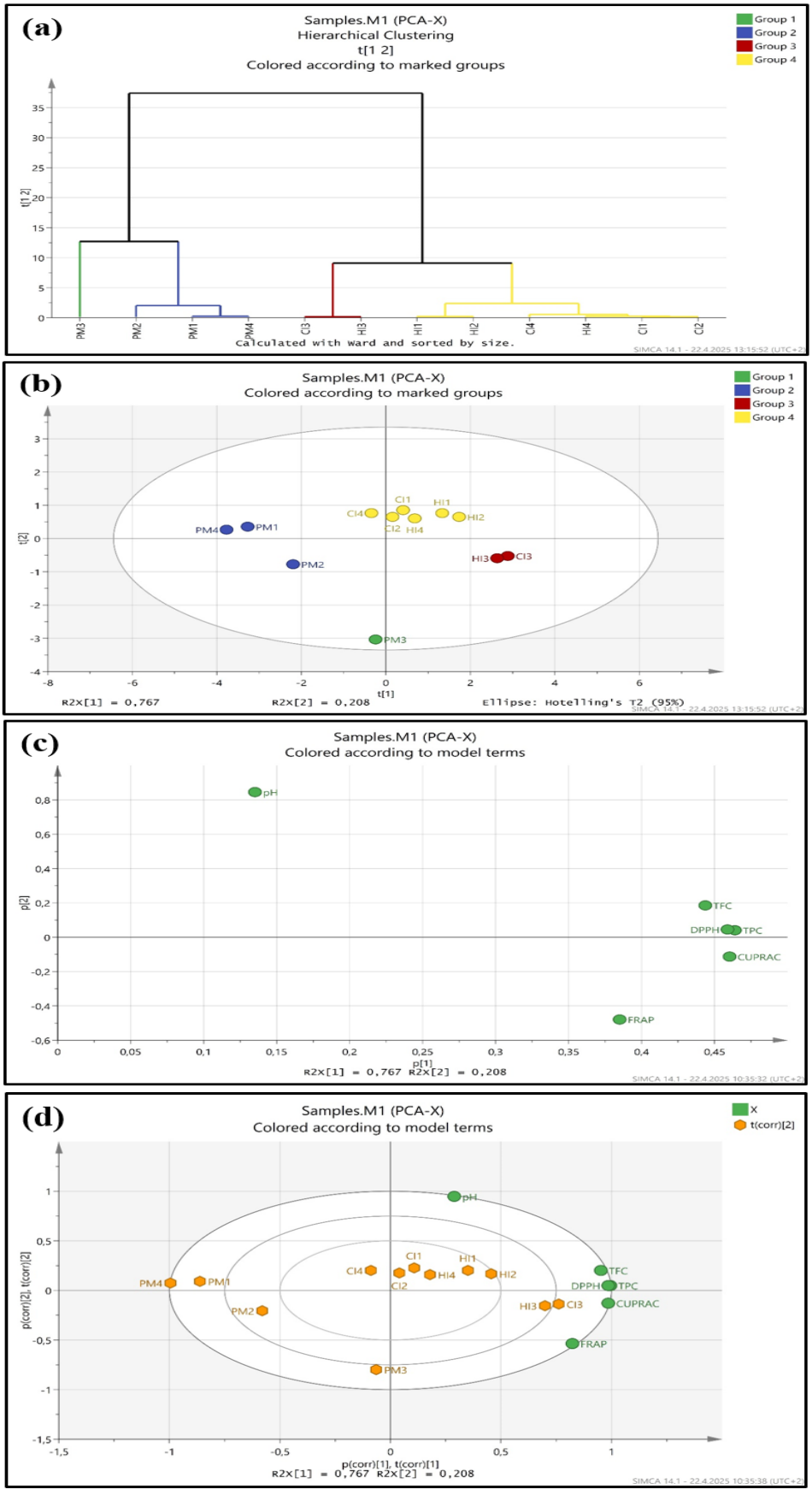


Figure 5. Dendrogram (a), score scatter plot (b), loading scatter plot (c), and biplot (d) of the principal component analysis (PC1 vs. PC2) on pH and bioactivity characteristics of experimental samples (Abbreviations; PM: Plant materials, CI: Cold infusions, HI: Hot infusions, 1:Walnut leaf, 2: Cinnamon, 3: Clove, 4: Cardamom)

CONCLUSION

This study was conducted to comparatively evaluate bioactivity, physicochemical, and sensory characteristics of hot (90 °C) and cold (25 °C) infusions prepared from the walnut leaf tea (WLT) enriched with cinnamon, clove, and cardamom (20%, w/w). Additionally, the bioactivity and quality characteristics of the plant materials (walnut leaf and spices) used in the preparation of the infusions were also investigated. The results indicated that cloves had the most distinct and strong antioxidant activity, followed by cinnamon, walnut leaf and cardamom. The addition of clove to infusions caused a significant increase in the total phenolic content, total flavonoid content, and antioxidant activity. The hot infusion was more efficient for the extraction of phenolic compounds, thus presenting a higher content of antioxidants. Indeed, strong correlations between the TPC and antioxidant activity were detected (r = 0.92, 0.99, and 0.94 for DPPH•, CUPRAC, and FRAP, respectively). PCA showed that clove dramatically affected the antioxidant activity of WLT infusions. The addition of spices significantly affected the pH value, color parameters, and sensory characteristics of the WLT infusions. The total sensory score results revealed that the WLT infusion enriched with cloves was most appreciated, followed by tea with cardamom, tea with cinnamon, and control tea. Conclusively, hot WLT infusions (plain or with spices) that have the potential to contribute natural antioxidants to the diet. Furthermore, this research may be useful for the development of a new type of medicinal herb tea product.

Declaration of interests

The author declares there is no conflict of interest.

Author Contributions

Mehmet Ali SALIK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Resources, Writing– original draft, Writing – review & editing.

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Original Article

Landscape Design Process and Implementation for Detached House Gardens Suitable for Continental Climates

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ABSTRACT

People's interest and concern for green areas, their desire to create their own gardens and landscapes, and their passion for living and waking up in the green bring together the dream of a house with a garden. In addition, Turkey has witnessed major earthquakes due to its active fault lines. Interest and concern for detached houses has increased much more on this occasion. Since construction companies care about this demand, detached house constructions have started to increase. Currently, each house has to have its own green area and garden. In this study, a detached house with a total area of 270 m^2 and a 135 m^2 base area within a 500 m^2 area and a 365 m^2 garden were built and the landscaping project and plant design application were carried out in Bingöl, a city with continental climate characteristics. The photographs of the study were recorded step by step and criticisms and evaluations were included in terms of being an example for plant design throughout the province and similar climates.

Key words: Bingöl, Cold climate, landscape project, plant design, Villa garden designe

Karasal İklimlere Uygun Müstakil Ev Bahçesi Peyzaj Tasarım Süreci Ve Uygulaması

ÖZ

İnsanların yeşil alanlara olan ilgi ve alakası, kendi bahçelerini ve peyzajlarını oluşturma isteği, yeşilin içinde yaşama ve uyanma tutkusu bahçeli bir ev hayalini birlikte getirmektedir. Bunun yanı sıra Türkiye sahip olduğu aktif fay hatlarından dolayı büyük depremlere şahitlik etmiştir. Müstakil evlere olan ilgi ve alaka bu vesile ile çok daha fazla artmıştır. Yapı firmaları bu talebi önemsediğinden, müstakil ev inşaatları artmaya başlamıştır. Hali hazırda her evin kendine has yeşil alanı ve bahçesi olmak durumundadır. Bu çalışmada karasal iklim özelliklerini taşıyan Bingöl kentinde 500 m^2 lik bir alan içerisinde 135 m^2 taban alan toplamda 270 m^2 büyüklüğünde bir müstakil ev ve 365 m^2 lik bahçesinin peyzaj projesi ve bitkisel tasarım uygulaması yapılmıştır. Yapılan çalışmaya ait fotoğraflar aşama aşama kaydedilerek bitkisel tasarımda il genelinde ve benzer iklimlere örnek olması açısından kritikler ve değerlendirmelere yer verilmiştir.

Anahtar kelimeler: Bingöl, Bitkisel tasarım, soğuk iklim, peyzaj proje, villa bahçe düzenlemesi

INTRODUCTION

Human beings have built houses for the problem of shelter, which is one of their basic needs. They are the smallest shelters at the level of the characteristics of the structures. These structures are not only physical, but also places where people's other desires and needs are met (Rapoport, 1969). The role of houses for people is very big. It is not possible to think of these structures, which reflect the style of people who carry a large part of their lives in houses, separately from the environment they are located in. Structures and nearby parts should complement each other (Şahin and Çalık 2021). It is not possible to think of the houses where people live separately from their immediate surroundings. Since the gardens of houses are positioned together, the house

garden and the house cannot be thought separately. House gardens are a part of the person's socioeconomic status, lifestyles and cultural activities (Bilir 2019).

In terms of earthquake maps, Turkey is located on the Alpine-Himalayan earthquake fault zone in the Mediterranean Region and is one of the three most important earthquake zones in the world (Bikçe, 2017). More than 200 earthquakes have occurred in Turkey since the first quarter of the 1900s, and these earthquakes have caused the deaths of approximately 86 thousand people (Altun, 2018). When the loss of life in the earthquakes that occurred in 2020 and 2023 is added to this statistical data, unfortunately this figure exceeds 150 thousand. It has been stated that one of the precautions that can be taken against earthquakes is to prefer a transition to horizontal architecture, to abandon high-rise buildings and to turn to detached buildings (Edemen et al. 2023).

In order for people to live happily, comfortably and safely in houses, the surroundings as well as the house need to be organized. Today, residential gardens have gained importance in order to satisfy people's longing for decreasing green areas, to increase their relationship with nature and to add aesthetic value to houses (Taşkan, 2014). In this respect, houses and gardens complement each other and cannot be considered as separate from each other. Since prehistoric times, houses and gardens have developed and changed together in a way that shapes each other. In this context, the garden is an extension of the house; it has become an important and indispensable space where socialization is carried out together with the priority of work production; and where family members can fulfill their recreational needs with different actions (Altınçekiç and Şentürk 2017). In the process we live in, the importance of residential gardens has increased in order to satisfy the longing for green and to add visual value to houses as a result of the decrease in green areas and the increase in urban spaces. Residential gardens can be an element that meets the recreational needs of the individuals they live in and shows their status and lifestyle (Bhatti 2006).

The house is a whole perceived with its environment. The principles of housing design show a parallelism within its environment. The reflection of the changes in the production processes depends on the planning principles, not the plan. While the formation of the plan depends on the social culture, the elements used during the implementation of the plan and the external environment affecting the designer in the planning process depend on economic and social inputs (Yegena, 1997). The characteristics of the housing user are determined by age, education level, gender, socioeconomic structure, sociocultural structure, expectations, experiences, lifestyle and worldview. The same characteristics are valid for the residential garden user. Each house and its garden user has different characteristics. Residential gardens are in a different place, with different topographic features, different climatic features and different soil features (Demirarslan, 2005; Kumbasar, 2008; Şahin and Çalık 2021). It has been stated that four main functions such as the main entrance area, work and service area, general living area and private living area should be taken into consideration in determining the usage status in house and garden planning (Korkut 2002; Yılmaz 2007). Residential gardens are designed according to the expectations and requests of the homeowners. While performing their duties, the designer should make a design that prioritizes sustainability in addition to a functional and aesthetic design by considering the user expectations (Yılmaz 2007).

Table 1. Designe principles and elements

Design Principles	Design Elements
Line	Repetition-Rhythm
Texture	Spaced Repetition
Shape-Form	Balance
Scale	Contrast
Interval	Harmonization
Color	Dominance
Light-Shadow	Unity
Emphasis	Appropriateness
Sequence	Hierarchy
Movement	Wholeness

Of course, while doing these, the geography where the residential garden is located, climate, temperature, soil characteristics and the ecological requests of the plants that make up the garden should be taken into consideration and the design should be conveyed to the garden owner in an appropriate language and a common point should be reached. In order to obtain the desired result from landscaping works, it is necessary to know the definition of design, its principles and elements and the design process. When a good design product emerges, it means that the principles and elements are definitely included in that design product. Otherwise, the

resulting product is plain, useless and far from aesthetics. In other words, areas created without considering design principles and elements cannot go beyond being unpleasant and unpopular works that are not at peace with the users. We can list these principles and elements as follows on table 1. (Yılmaz and Yılmaz, 2004).

Design of Detached House Gardens

It has been stated that people shape their homes in different dimensions according to their own needs, their own behavior and lifestyle, with the geography, climate and cultural factors they are in, with different visual, auditory and aesthetic odors, and with conditions related to the humidity, dryness, heat and light of the air (Erzen 2006). For example, the summer and winter usage status of the garden and house, the number of adults and children living in the house, their age, gender and occupations, which architectural and green building elements the household prefers (garage, pool, pergola, children's play elements, fruit and vegetable garden, etc.), which types of plants and colors they like, whether they will personally deal with gardening, how much budget they can allocate for this work, etc. should be clarified. Thus, the uses planned to be brought should be placed on the plan as circular spots, without scale, but within certain proportions, considering their relationships with each other. The ideal function diagram forms the basis for the later stages. Therefore, this diagram should be prepared meticulously, taking into account all kinds of features (Çınar 2008).

There are 3 specific components in a detached house garden landscape design. These are the customer, the area and the house. No customer, area or house is the same. Each customer has their own characteristics, desires, wishes, lifestyle, each area is different from each other with its topography, vegetation, landscape, surroundings and other elements. Each house is also different and unique from each other in terms of architectural character, floor plans, decoration, furniture and accessories. The house garden, which the landscape architect should design by considering these 3 main elements, will reflect the lifestyle and values of the users (Bilir 2019).

Detached house gardens generally consist of 3 parts. These are;

- Front garden
- Back garden
- Side gardens (Booth and Hiss 2012).

It can be listed as. Of course, this is not valid for every residential garden. The land structure changes depending on the architecture of the houses, their positioning within the land and most importantly the size of the garden. There are many factors that the landscape architect should consider in the landscape design of a detached residential garden. Some of these are:

- The client's wishes and requirements
- Budget limits
- Existing opportunities and restrictions in the area
- Interior-exterior relationship (rooms, doors, windows)
- The architecture of the house (Bilir 2019).

Although there are some design criteria, the expectations of the homeowner are at the forefront. While some users want to plant for screening purposes in the front garden, there may be a possibility of blocking the existing view. The person may want to completely restrict the garden of his house from the outside. In such matters, the designer's duty is to realize the person's wishes by using appropriate plants. Similar situations are valid for the backyard and side garden. According to the design criteria, the backyard is separated as a living space. However, the homeowner may want to carry out this activity in the front garden. From this point of view, the designs of detached house gardens differ greatly from each other. Indeed, in the landscape design of detached house gardens, the most important factors for landscape architects are the wishes of the homeowner, the amount that can be paid for the design, the architecture of the detached house and the ecology of the region. The success of a landscape design is possible by correctly choosing and positioning the plant material used.

Plant design and its principles

Plants are the basic building blocks of landscaping studies within the scope of Landscape Architecture. They have an important place in both urban and rural area planning and design. According to Acar et al. (2003), plants have the most important place in landscape architecture studies. Plants play a major role especially in the creation of aesthetic and functional spaces and they play an important role in softening hard surfaces and materials such as stones, walls and structures used in landscapes. Plants soften hard materials and make them more natural and closer to humans. Plants realize these features only over time and add the fourth dimension, time, to the landscape. When plants are used as a composition, some design principles affect them. These principles play a role in many compositions from the juxtaposition of plants to their intended use. Plants offer the designer a wide range of options in terms of size, shape, texture, color, movement, light and shadow effects

(Aslanboğa 1997). According to Hannebaum (1998), plant design principles are; form, texture, color, simplicity, variability, emphasis, balance, order and scale (Eroğlu et al. 2005).

MATERIAL AND METHODS

The detached house in question is a 270 m^2 house built on a 135 m^2 area within a 500 m^2 plot in the province of Bingöl in the Eastern Anatolia Region and has a 365 m^2 green area. It is known that at the beginning of the project, the land was empty, the soil was not leveled and there was only a connection road made of interlocking stones from the garden entrance to the house entrance (Figure 1-2).

Figure 1. Paving stone path and side garden connecting the garden entrance to the house entrance.

Figure 2. Front garden and sidewalk

Bingöl Province is located in the Upper Euphrates section of the Eastern Anatolia Region. It is surrounded by Muş to the east, Erzurum and Erzincan to the north, Tunceli and Elazığ to the west, and Diyarbakır to the south. Bingöl Province is located between the east longitudes of 41º-20' and 39º-56º and the north latitudes of 39º-31' and 36º-28º. Apart from the city center, there are 7 districts: Adaklı, Genç, Karlıova, Kiğı, Solhan, Yayladere and Yedisu. The city center is established on a plain overlooking a branch of the Göynük River, which meets the Murat River near Genç District, in the northwest corner of the Çapakçur Plain at an altitude of 1151 meters above sea level (Caf and Yılmaz 2024).

Bingöl has a continental climate. Winter temperatures are quite low, while summer temperatures reach high values. The hottest months are July and August, while the coldest month is January. Annual Average Temperature: 12.2°C, Average High Temperature: 18.7°C, Average Low Temperature: 6.7°C, Average Sunshine Duration: 6.2 hours/day, Annual Average Number of Rainy Days: 108.6 days, Annual Total Precipitation: 945 mm(Table 2) (Anonymous 1).

Table 2. Bingöl Climate Data Table

Parameter	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Average Temperature (°C)	-2.2	-1.0	4.3	10.9	16.2	22.1	26.7	26.5	21.3	14.3	6.8	0.8	12.2
Average High Temperature (°C)	2.4	4.0	9.6	16.9	22.9	29.5	34.6	34.8	29.8	21.7	12.7	5.3	18.7
Average Low Temperature (°C)	-5.7	-4.8	0.0	5.8	10.2	14.8	19.1	18.7	13.7	8.3	2.3	-2.6	6.7
Average Sunshine Duration (hours/day)	3.4	4.5	4.8	5.6	7.1	9.1	9.4	9.0	8.1	6.1	4.5	3.3	6.2
Average Rainy Days	12.88	12.36	14.08	14.67	13.67	5.31	1.77	1.38	2.47	8.16	9.23	12.58	108.6
Monthly Total Precipitation (mm)	138.5	128.1	134.8	115.2	77.7	20.3	7.1	4.3	12.8	64.0	107.9	134.3	945.0

The highest recorded temperature in Bingöl was 42.0°C in July (26.07.2001), while the lowest recorded temperature was -25.1°C in December(27.12.1992). Winters are characterized by severe cold, whereas summers experience extremely high temperatures(Table 3). Temperature Records (1961 - 2024)

Table 3. Bingöl Extreme Temperature Data Table

Parameter	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Highest Temperature (°C)	13.3	16.2	22.9	30.5	33.9	38.0	42.0	41.3	38.1	32.1	25.5	22.8	**42.0**
Lowest Temperature (°C)	-23.2	-21.6	-20.3	-9.2	1.0	3.5	8.8	7.8	4.2	-2.4	-15.0	-25.1	**-25.1**

Project sheet drawn in line with user requests and The following criteria were taken into consideration when designing the Project;

- Determination of Functional Garden Areas (Rest, Play, Vegetable Garden, etc.)
- Balance of Hard Ground and Soft Ground
- Landscape project map has been drawn in line with principles such as Arrangements to Reduce Wind and Sun Effects
- Drought and Frost Resistant Plants
- Seasonal Plant Selection and Color Harmony
- Use of Native and Adaptive Plants(Figure 3).

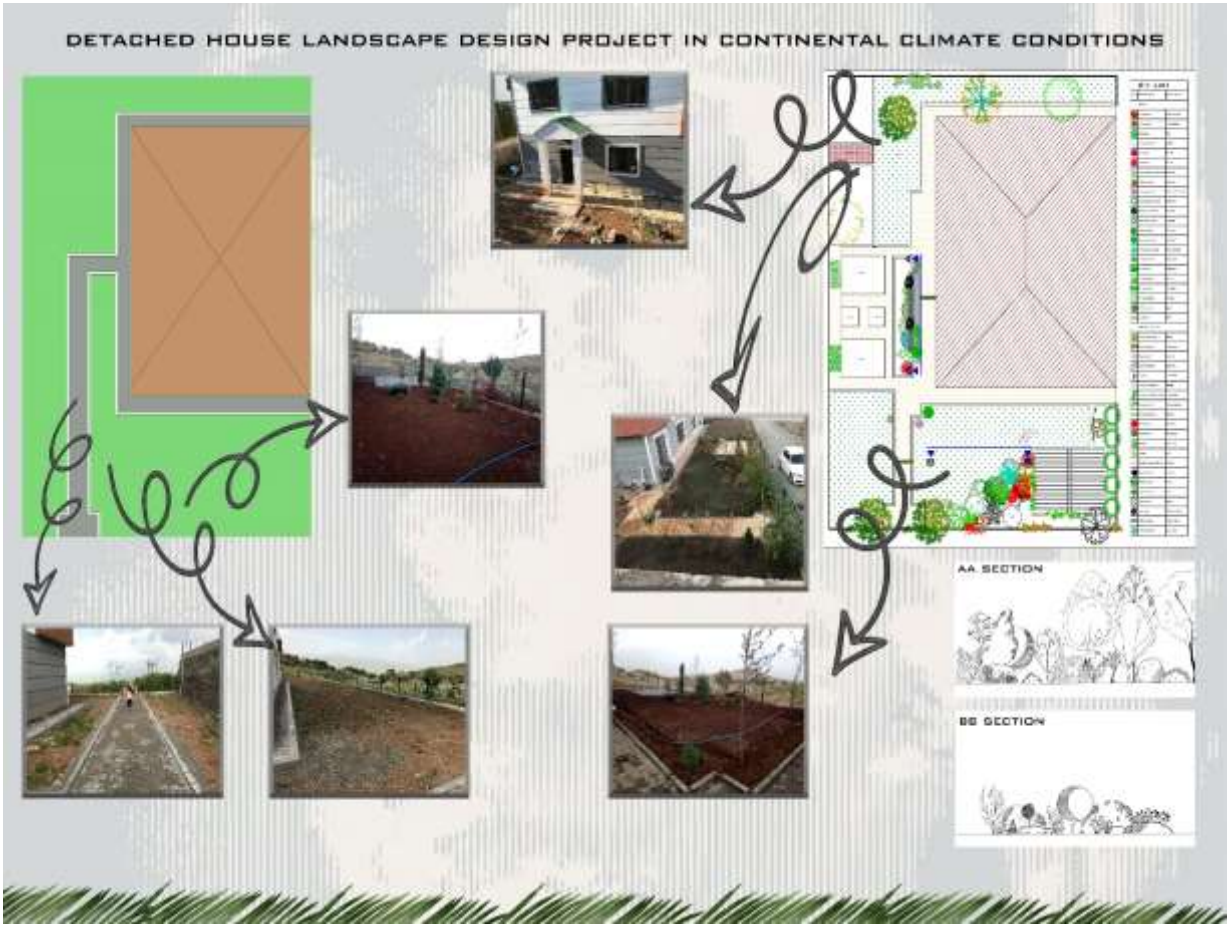

Figure 3. Project sheet

As seen in the project, 3 sides of the house are open green areas. In the west, in the backyard, 2 fruit trees were used, plum and apricot (Prunus domestica, Prunus armeniaca). In the grass area in the front, ornamental apple (Malus hybrida) and quince (Cydonia oblonga) were used, on the edge of the children's playground. In the

north, in the front garden, a hobby garden was designed in the parts facing the kitchen. Again, in the southwest of the front garden, a barbecue and fireplace area were designed (Figure 4).

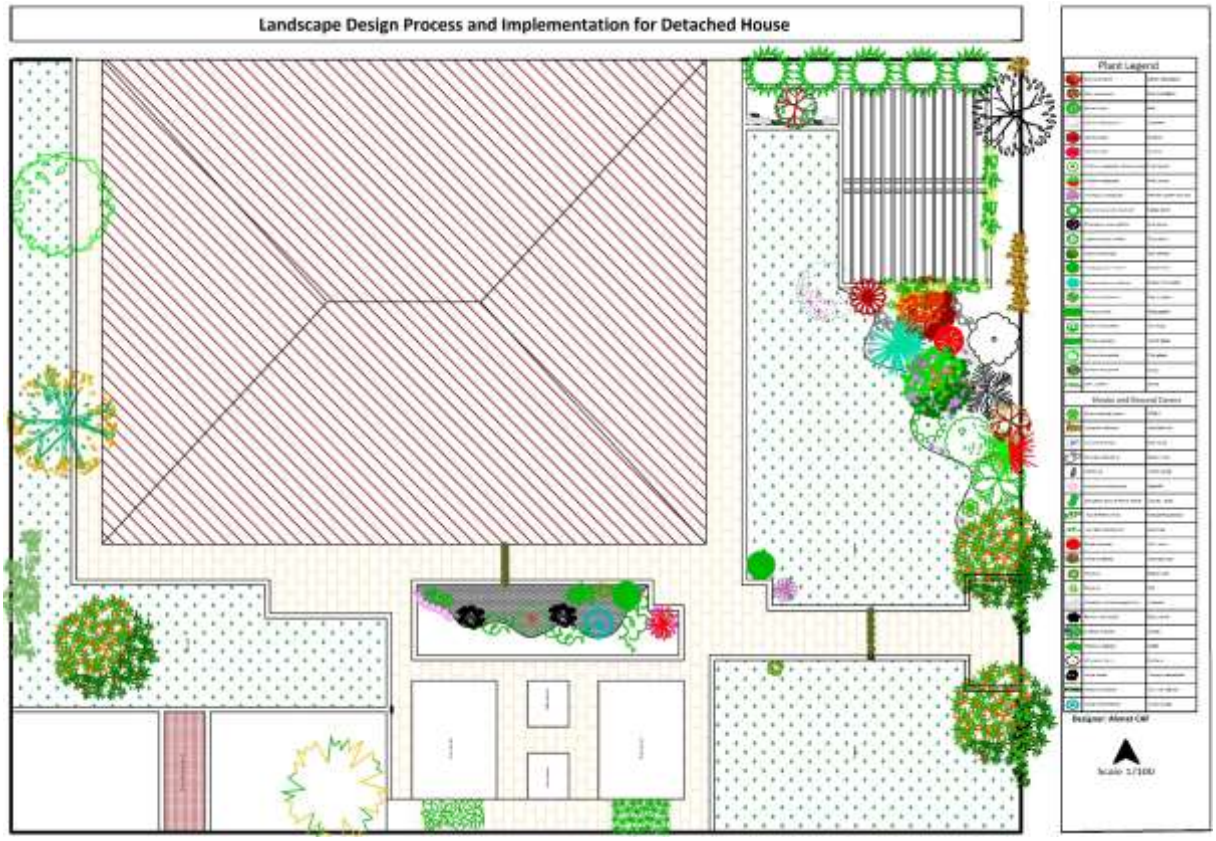

Figure 4. Landscape project and plant design

Right in front of the kitchen window, ivy roses, cane roses, thyme, carnation juniper, seasonal flowers Yucca filementosa margarite daisies and cotinus coggygria royal purple were used (Figure 5).

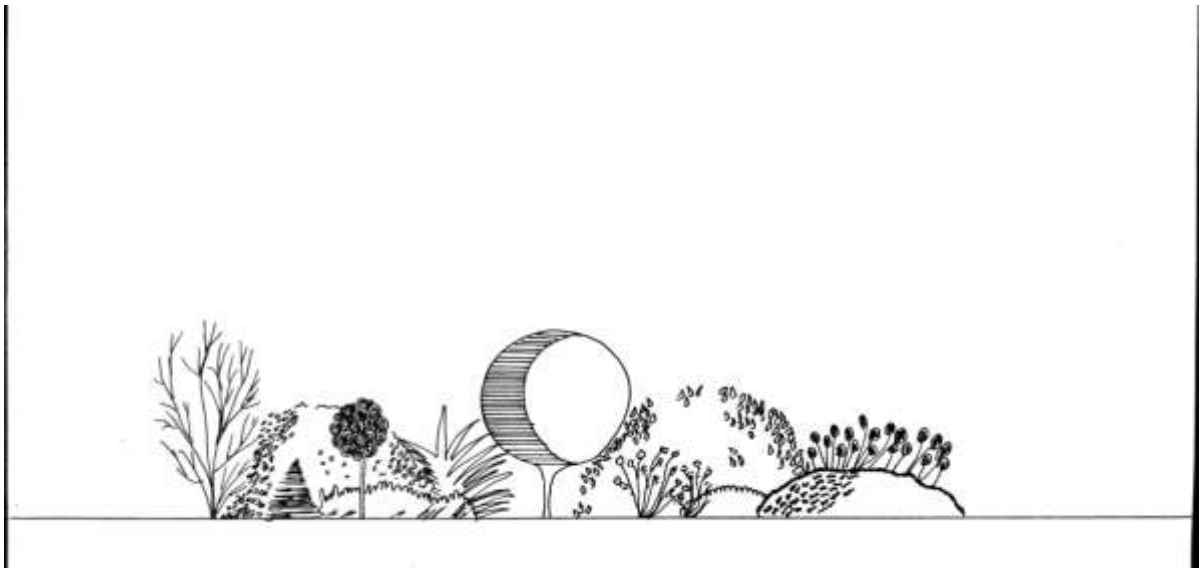

Figure 5. Front yard planting design

The large side garden to the east overlooks the kitchen and living room. 4x3m^2 pergola was designed in this section as a sitting area. It constitutes the richest part of the garden in terms of plant design (Figure 6). In this area, Syringa vulgaris, Viburnum opulus, Berberis thunbergii 'Atropupurea', Spiraea vanhouttei, Photinia

serratifolia, Prunus ceracifera, Buxus sempervirens, Picea pungens glauca globosa nana, Picea glauca 'Conica', Betula lutea, Acer campestre, Chrysanthemum sp., Senecio sp., Hyacinthus sp (Figure 6).

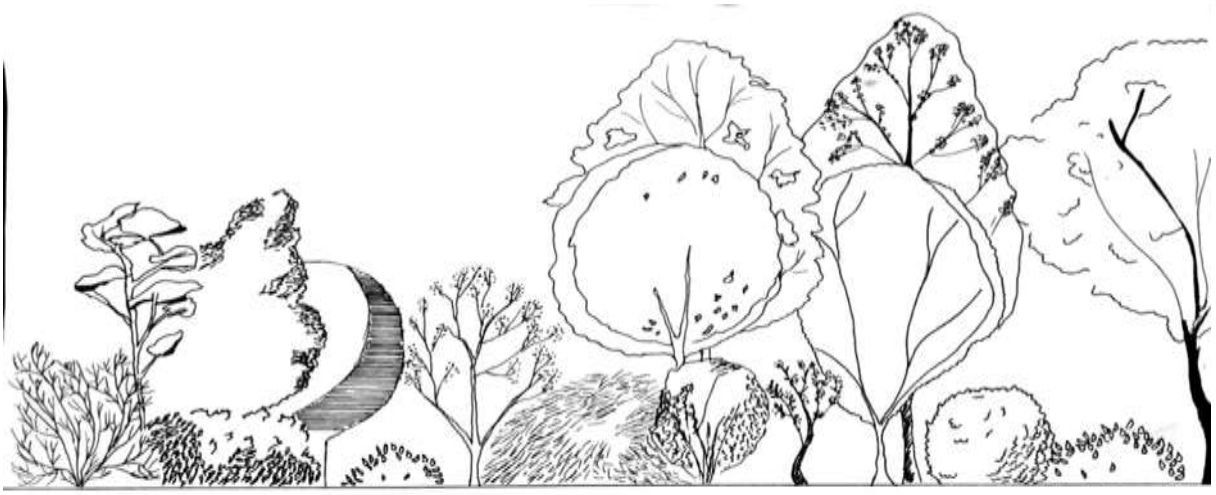

Figure 6. Side garden planting design.

RESULTS and DISCUSSION

The climate conditions of Bingöl province are close to the average values of Turkey. Therefore, the plant species used in the study can be used in many provinces with similar climates. Santolina Chamaecyparissus, known to be a temperate climate plant, was used successfully. No problems were experienced in all plants used for three years despite the harsh winters. Since the woody plants are resistant to pruning, they were kept in the desired form. The designed and applied plant composition added aesthetics to the garden in all four seasons. While Cercis ciliquastrum used at the entrance of the pergola built as a sitting area heralds spring, the scent added to the space by Eleagnus angustifolia and Lonicera caprifolium attracts users. A map consisting of the photographs obtained as a result of the project application was created (Figure 7).

Figure 7. Current status of the project after 3 years

PLANT LIST					
Symbol	Plant Name	Number	Symbol	Plant Name	Number
	Trees			Shrubs and perennial flowers	
	Acer palmatum	1		*Buxus sempervirens*	1
	Acer campestre	1		*Campsis radicans*	3
	Betula lutea	1		Chrysanthemum	10
	Cercis siliquastrum	1		Cineraria Maritima	3
	Cornus alba	1		*Dahlia sp.*	5
	Cornus mas	1		*Dianthus caryophyllus*	5
	Cotinus coggygria 'atropurpurea'	1		Juniperus procumbens 'Nana'	1
	Cotinus coggygria	1		Leucanthemum sp.	10
	Crataegus laevigata	1		Lonicera caprifolium	3
	Cupressocyparis leylandii	5		Photinia fraseri	1
	Elaeagnus angustifolia	1		Rosa multiflora	2
	Lagerstroemia indica	1		Rosa sp.	4
	Malus floribunda	1		Rosa sp.	2
	Picea glauca 'conica'	2		Santolina chamaecyparissus	2
	Picea pungens 'globosa'	1		Spirea vanhouttei	1
	Prunus armeniaca	1		Syringa vulgaris	1
	Prunus avium	1		Thymus vulgaris	3
	Prunus cerasifera	1		Viburnum tinus	1
	Prunus cerasus	1		Vinca majör	2
	Prunus domestica	1		Wisteria sinensis	1
	Sorbus aucuparia	1		Yucca filamentosa	1
	Vitis vinifera	1			

Figure 8. Plants list and number of plants used

CONCLUSION

The landscape design and plant applications implemented yielded successful results in both aesthetic and functional terms. Important findings were obtained on how sustainable landscape design can be applied in regions with continental climates such as Bingöl. The project sets an example for landscape arrangements to be made in regions with similar climate conditions. This study was conducted to prevent plant design errors frequently made in small home gardens. For example, a user who wants to plant a plane tree (Platanus orientalis) in a detached home garden with a green area of 60 m^2 should be told in technical language why not to use it. Or, in a region with a water problem, the costs and difficulties of maintenance, irrigation, pruning, fertilization of grass areas should be explained to the user. It will be useful in terms of providing literature on plant materials that can be used in climates with similar climates. Among the woody plants used; *Acer sp., Betula sp., Cornus alba, Cotinus sp.* were used for their spring and autumn leaf coloration. *Prunus sp. and Malus sp.* were used for their flower and fruit effect. *Juniperus sp. and Picea sp*. were preferred for their form. *Lonicera sp., Syringa sp.*

Eleagnus sp., Rosa sp. were used for their flower scent and form. Seasonal flowers were preferred for their color, scent and form features. All of the plants used were adapted to the ecological conditions of the province.

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Ahmet CAF :Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; writing— original draft; writing—review and editing.

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Türkiye Florasındaki Dorycnium Miller (Fabaceae) Cinsinin Taksonomik Özellikleri ve Morfolojisi

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ÖZ

Bu çalışmada Türkiye'de doğal olarak yayılış gösteren *Dorycnium* (Fabaceae) cinsine ait taksonların sistematik ve morfolojik özellikleri ile Türkiye'deki dağılımları incelenmiştir. Cinse ait türlerin Türkiye'de doğal yayılış ortamlarından morfolojik karakterlerini yansıtan özellikleri korunarak toplanan örnekleri üzerinde ayrıntılı morfolojik incelemeler yapılmıştır. Cinse ait tüm taksonların deskripsiyonları genişletilmiş, tür teşhis anahtarı yeniden düzenlenmiş, habitat özellikleri, IUCN tehlike kategorileri, coğrafik yayılışları belirtilmiştir. Ayrıca, elektron mikroskobu (SEM) incelemeleri ile polen ve tohum mikromorfolojileri de araştırılmıştır. Yapılan bu revizyon çalışması ile Fabaceae familyası içerisinde yer alan *Dorycnium* Miller. cinsinin sistematik problemleri giderilmiş, Türkiye Florası için yeni kayıt olan *Dorycnim hirsutum* var. *syriacum* taksonu güncellenmiştir. *Dorycnium* cinsi Türkiye'de 12 takson ile temsil edilmekte olup endemik takson sayısı 5 olarak belirlenmiştir.

Anahtar kelimeler: *Revizyon, Dorycnium, Fabaceae, Türkiye.*

Taxonomic and Morphological Characteristics of the Genus Dorycnium Miller (Fabaceae) in the Flora of Türkiye

ABSTRACT

In this study, the genus *Dorycnium* belonging Fabaceae family has been investigated in terms of their systematic and morphological with their distribution in Türkiye. On the samples which were reflecting the morphological properties of species belonging the genus, collected from natural distribution areas in Türkiye, detailed invesitigation were carried out. After these examination, the descriptions, habitat characteristics, geographical distribution and IUCN categories have been determined, and additionally, species identification keys has been rearranged. On the other hand, the seed and pollen micromorphologies was also investigated by scanning electron microcope (SEM) examination. The systematical problem of the genus *Dorycnium* Miller. within Fabaceae family were resolved with this revision study and a new record for the Flora of Turkey, *Dorycnium hirsutum* var.*syriacum*, has been determined. The genus *Dorycnium* are represented with 12 taxa in Türkiye and among them 5 taxa are endemic.

Key words: *Revision, Dorycnium, Fabaceae, Türkiye*

GİRİŞ

Dorycnium Mill. cinsinin ait olduğu Fabaceae familyası Angiospermae (Kapalı tohumlular) bitki grubunun Orchidaceae ve Asteraceae familyalarından sonra 3. en büyük familyasıdır. Ayrıca bu familya üyeleri Poaceae familyasından sonra ekonomik önemi olan 2. büyük familyadır (Doyle ve ark., 2000; Lewis ve Schrire, 2003; Wojciechowski, 2003). Dünya üzerinde 750 cins ve yaklaşık 20.000 tür içermektedir (Allen ve Allen,1981; Denarie

ve ark., 1992). Türkiye Florası'nda ise 83 cins ve 1145 türle temsil edilmekte olup endemizm oranı % 43'tür (Davis, 1970; Dönmez ve Uğurlu Aydın 2018). *Dorycnium* cinsi dünya üzerinde 13 tür ile temsil edilir, cinsin gen merkezi Akdeniz bölgesidir (Gillett, 1959; Demiriz, 1970; Greuter ve ark., 1989). Genel olarak güneşli alanları, kumlu ve verimsiz toprakları sever. Cinse ait türlerin köklerinde barındırdığı *Rhizobium* bakterileri azot döngüsünde rol alır (Allen ve Allen,1981; Slavik, 1995). *Dorycnium* cinsini ilk olarak tanımlayan Tournefort (1700) olmuştur. Bazı bilim adamları yaptıkları filogenetik çalışmalar ile tüm *Dorycnium* türlerini *Lotus* L. cinsine aktarmışlardır (Allan ve ark., 2003; Sokoloff, 2003). Ball (1968) ve Isley (1981) ise *Dorycnium* cinsini, *Lotus* cinsinden ayırarak Lotae oymağında ayrı bir cins olarak değerlendirmişleridir. Türkiye'de *Dorycnium* cinsinin ilk revizyonunu yapan Demiriz (1969) iki seksiyona dahil 6 tür ve 3 alt tür tanımlamıştır. Daha sonra tanımlanan yeni türler ile takson sayısı 11'e ulaşmıştır (Vural, 1983; Şahin ve ark., 2024).

Bu çalışmada Türkiye Florası'nda (Davis, 1970) yer alan Fabaceae familyasına ait *Dorycnium* Mill. cinsine ait sistematik problemlerin giderilmesi amaçlanmıştır. Çalışma sonucunda cinsin tür teşhis anahtarı revize edilerek yenilenmiş, tüm taksonların deskripsiyonları yeniden düzenlenerek genişletilmiştir. Ayrıca cinse ait taksonların IUCN tehlike kategorileri, coğrafik yayılışları belirtilmiş ve morfolojik karakterlere ait fotoğrafları da verilmiştir.

MATERYAL ve METOT

Türkiye'de doğal olarak bulunan *Dorycnium* cinsine ait türleri tespit etmek için 2011-2014 yıllarında Mayıs-Ekim aylarında arazi çalışmaları yürütülmüş ve Türkiye'de 89 farklı lokalitede bulunan popülasyonlardan 550 bitki örneği toplanmıştır. Morfolojik incelemeler araziden toplanan türlere ait herbaryum materyalleri kullanılarak yapılmıştır. Bu çalışma yayına hazırlanırken tanımlanan yeni tür *D.vuralii* için Şahin ve ark. (2024)'nın çalışmasından faydalanılmıştır. Tür teşhisleri yapılırken başta Türkiye Florası (Davis, 1975) olmak üzere, Rusya Florası (Komarov, 1945), Avrupa Florası (Tutin ve ark., 1976), İran Florası (Rechinger, 1984), Suriye Florası (Post, 1932)'ndan yararlanılmıştır. Ulusal herbaryumlar (AEF, ANK, EGE, GAZI, HUB, ISTE, ISTO, KNYA) ve yurt dışı herbaryumlar da (E, G ve KEW) ziyaret edilerek *Dorycnium* cinsine ait bitki örnekleri ayrıntılı olarak incelenmiştir (Güner ve Ekim, 2014). Bitki isimleri Brummitt ve Powell (1992) ile IPNI 2020'den kontrol edilerek verilmiştir. Elektron mikroskobu çalışmalarında herbaryum materyali haline getirilen bitki örneklerindeki polenler ve tohumlar kullanılmıştır. Polenlerin incelenmesinde; Erdtman (1966), Punt ve ark. (2007) ve Faegri ve Iversen (1992)'in palinolojik terminolojisi, tohumların mikromorfolojik değerlendirilmelerinde Barthlott (1981 ve 1984)'un çalışmalarından yararlanılmıştır.

Dorycnium cinsine ait tür ve tür altı kategorilerin tehlike düzeyleri IUCN kriterlerine göre hazırlanmıştır (IUCN, 2021). IUCN kategorisi ve tehdit durumu Uluslararası Doğa Koruma Birliği (IUCN) tarafından belirlenen kriterlere göre canlı türlerinin populasyon bilgilerine dayanılarak kategorize edilmiştir. Bu kategoriler belirlenirken bitki türünün bulunduğu lokalite, populasyon ve birey sayısı, habitattaki biyotik ve abiyotik unsurlar, tür devamlılığını etkileyen biyolojik yapı vb. özellikleri dikkate alınmıştır. Türkiye Bitkileri Kırmızı Kitabı'nda (Ekim ve ark., 2000) tehlike kategorisi tanımlanmayanlar ve yeni kayıt taksonun tehlike kategorisi belirlenmiştir. Bu çalışmada her takson için ayrıntılı tür deskripsiyonu yapılarak; çiçeklenme zamanı, yetişme ortamı ve yüksekliği, endemizim durumu, fitocoğrafik bölgesi, tehlike kategorisi ile polen ve tohum özellikleri verilmiştir. Bu çalışma sırasında toplanan örnekler KSÜ Fen Fakültesi Biyoloji Bölümü Herbaryumunda (KSUH) muhafaza edilmektedir.

BULGULAR ve TARTIŞMA

Dorycnium Cinsinin Taksonomik Özellikleri

Çok yıllık otsular veya küçük yarı çalımsılar, tabanda odunsu yapı var veya yok, yapraklar 5-7 yaprakçıklı, rakisler varsa boyu eninden uzun veya yok, stipullar çok küçük. Çiçek kümesi şemsiye şeklinde hemen hemen kapitat, çiçekler çok kısa saplı veya sapsız olup, involukrum brakteleri çok küçük, birleşik yada serbest, çiçek sayısı kadar veya az sayıda, kaliks eşit 5 dişli yada belirgin olmayan şekilde 2 dudaklı olup dişlerden 2 tanesi diğer 3'ünden daha geniş. Korolla; beyaz, pembe, pembemsi, parlak sarı yada kırmızı, ala uçta birleşik yada değil, karina uçları sivri değil ve bazen morumsu kırmızı renkte. Stamenler diadelfus halinde. Legümen meyve; dikdörtgenimsi, silindirik, küremsi veya yumurtamsı şekilde. Meyve içindeki bölümler enine dizilim gösterir ve meyve olgunlaştığında açılır veya açılmaz. Tohum sayısı 1-7 tanedir.

Türkiye'deki Dorycnium Cinsi Tür Teşhis Anahtarı:

1-Kaliks eşit yapıda 5 dişli; korolla kanatları uçta serbest; meyve 1-7 tohumlu, olgunlaştığında açılır veya açılmaz. **Sect. Bonjeania**

2-Yapraklar 5-7 yaprakçıklı, rakis 1-11 mm, çiçek kümesi 4 çiçekten fazla (4-47), meyve olgunlaştığında açılır veya açılmaz.....3

3.Çiçekler 9-16 mm; meyve 6-10 mm, olgunlaştığında açılmaz…… **hirsutum**
. Çiçekler 4-8 mm; meyve 4-14 mm olgunlaştığında açılır veya açılmaz.
4.Rakis 3-11 mm; meyve 8-14 mm, olgunlaştığında burularak açılır, tohum sayısı 3-7……**rectum**
4. Rakis 1-2.5 mm, meyve 4-10 mm, olgunlaştığında açılmaz, tohum sayısı 1-4……**graecum**
- Yapraklar 3-5 yaprakçıklı, rakis 2-5 mm, çiçek kümesi 3-6 çiçekli, meyve olgunlaştığında açılır…….. **vuralii**
Kaliks belirsizce iki dudaklı, üstteki 2 kaliks dişi alttaki diğer 3 dişten daha geniş; korolla kanatları uçta birleşik belirgin şekilde şişkin; meyve 1 tohumlu, olgunlaştığında açılmaz. **Sect. Dorycnium**
. Çiçek kümeleri hemen hemen sapsız, her bir yaprak koltuğunda 2- 3 çiçek kümesi bulunur….**axilliflorum**
. Çiçek kümeleri saplı ve yaprak koltuklarında tek çiçek kümesi bulunur
. Yaprakçıklar en fazla 5 mm genişliğinde, yanlardaki çiçekler uzun saplı ……**pentaphyllum**
. Yaprakçıklar 5-10 mm genişliğinde; yanlardaki çiçekler kısa saplı veya sapsız
7. Çiçekler; beyaz veya parlak sarı-beyaz renkte …… **amani**
7. Çiçekler; kan kırmızı renkte…… **sanguineum**

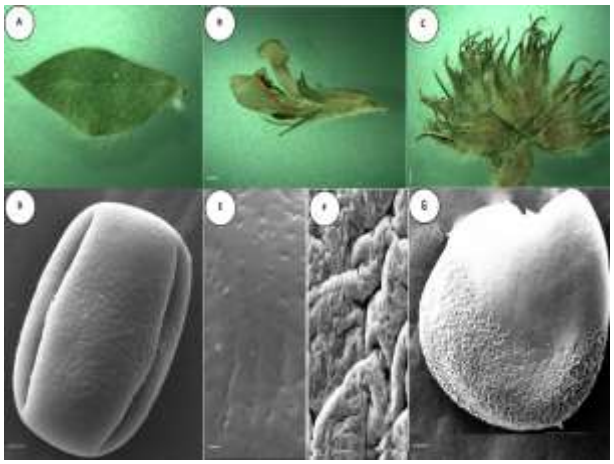
***Dorycnium hirsutum* (L.) Ser.**

Çok yıllık, küçük yarı çalı formunda. Gövde, 30-65 cm uzunluğunda, yoğun kısa yumuşak ve kısmen yatık tüylü, gövdenin üst kısmı alt kısmından daha tüylü. Yapraklar 5-7 parçalı ve 1-4 mm uzunluğunda kısa rakisli. Yaprakçıklar; oblong-obovat, 8-20 x 3-10 mm, yoğun halde yumuşak tüylü, mukronat. İnternodlar 1.5-5.7 cm. Çiçek kümesi şemsiye şeklinde hemen hemen kapitat, 4-11 çiçekli, pedonkül 0.7-4 cm. Pedisel kaliks tüpünden kısa, 1-2 mm. Kaliks; 6-12 mm uzunluğunda, yoğun yumuşak uzun tüylü, tüp düz bir şekilde 3-5.5 mm, pembemsi renkte, kaliks dişleri lanseolate-subulat şekilde, uçları morumsu kırmızı renkte, dişlerin boyu kaliks tüpünden biraz uzun, 3.5-6.5 mm. Çiçekler; beyaz veya pembe renkte, 9-16 mm, veksillum 12-16 mm, ala 10-11 mm ve uçta birleşik değil, karina 9-11 mm, karina uçları bazen morumsu kırmızı renkte. Ovaryum 4-5 mm, stilus 3 mm uzunluğunda. Legümen meyve, ovat-oblong 6-10 x 2-4.5 mm, gaga 4-4.5 mm uzunluğunda, uç kısımları morumsu kırmızı renkte, meyve olgunlaştığında açılmaz. Tohum; 2-7 adet, yüzey düz-retikulat, şekli oblong-reniform, 1.05 x 1.63 mm.

1. Bitki belirgin şekilde yoğun tüylü, çiçekler 9-16 mm, kaliks meyveden uzun 6-12 mm, legümen tipi meyve 6-10 mm. ……**var. hirsutum**
1. Bitki seyrek tüylü, çiçekler 6-13 mm, kaliks meyve ile aynı boyda 6-9 mm. …… **var. syriacum**

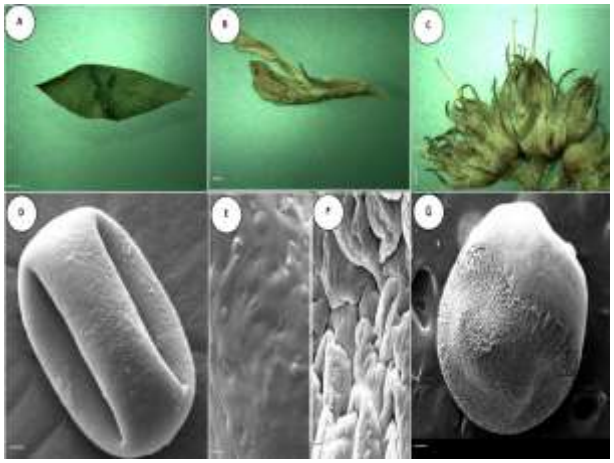
var. *hirsutum* (L.) Ser. in DC, Prodr. 2:208 (1825).

Çiçek açma zamanı: 4-6.
Habitat: Kalkerli ve dik yamaçlar, kuru tepeler, maki ve kızılçam ormanları, 1-900 m.
Endemizm durumu: Endemik değil
Fitocoğrafik bölgesi: Akdeniz elementi
Tehlike kategorisi: LC (Least Concern) Az tehdit altında
Polen Morfolojisi: Trikolporat - prolat (P/E:1.37), orta (P x E : 28.72 x 20.87 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları sivri; clg: 20.70 µm, clt: 0.76 µm. Porlar; belirgin, plg: 4.70 µm, plt: 4.55 µm, plg/plt: 1.03, sferoid, Tektat - Faveolat ve hafif rugulat, ekzin : 1.10 µm (Şekil 1).



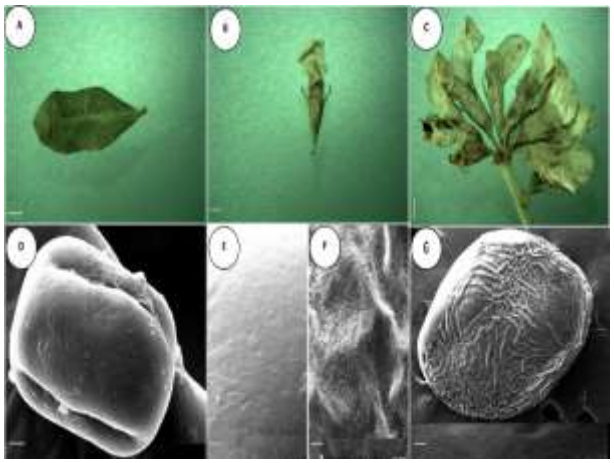
Şekil 1. *D. hirsutum'*a ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

var. *syriacum* (Boiss.) Boiss., Fl. Or. 2:161 (1872).
Çiçek açma zamanı: 4-6.
Habitat: Eğimler, kuru tepeler ve maki, 1-200 m.
Endemizm durumu: Endemik değil
Fitocoğrafik bölgesi: Doğu Akdeniz elementi
Tehlike kategorisi: VU (Vulnerable) Zarar görebilir
Polen tipi- şekli: Trikolporat - prolat (P/E:1.47), orta (P x E : 31.52 x 21.33 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları sivri; clg: 21.83 µm, clt: 0.72 µm. Porlar; belirgin, plg: 5.33 µm, plt: 5.16 µm, plg/plt: 1.03, sferoid, Tektat - Faveolat ve hafif rugulat, ekzin : 0,98 µm (Şekil 2).



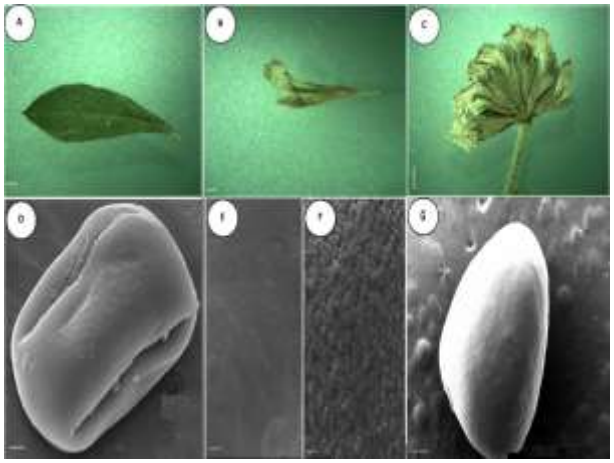
Şekil 2. *D. hirsutum* var. *syriacum'*a ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

Dorycnium rectum (L.) Ser. in DC., Prodr. 2:208 (1825).
Çok yıllık, otsu veya küçük yarı çalı formunda. Gövde, 35-100 cm uzunluğunda, seyrek kısa yumuşak ve yatık tüylü. Yapraklar 5-7 parçalı ve 3-11 mm uzunluğunda belirgin rakisli. Yaprakçıklar obovat'dan obovat-oblong'a kadar şekilli, 12-35 x 5-21 mm seyrek kısa yumuşak ve yatık uzun tüylü yada tüysüz, mukronat. İnternodlar 2-7 cm. Çiçek kümesi şemsiye şeklinde hemen hemen kapitat, 12-35 çiçekli, pedonkül 3-13 cm. İnvolukrum brakteleri çok küçük, çiçek sayısından az ve uçları morumsu kırmızı renkte. Pedisel kaliks tüpü ile aynı boyda veya biraz uzun, 1.5-2.5 mm. Kaliks; 3-4.5 mm uzunluğunda, yumuşak tüylü, tüp düz bir şekilde 1-2 mm, taban kısmı pembe renkte, kaliks dişleri subulat şekilde, uzunluğu 2-2.5 mm. Çiçekler; beyaz veya pembe renkte, 4-7 mm, veksillum 6-7 mm, ala 4-5 mm ve uçta birleşik değil, karina 4 mm. Ovaryum 5-6 mm, stilus 2-2.5 mm uzunluğunda. Legümen meyve, linear-silindirik, 8-14 x 1.5-3 mm, parlak görünümlü, gaga 3-4 mm uzunluğunda, meyve olgunlaştığında burularak açılır. Tohum; 3-7 adet, yüzey basit retikulat, şekli oblong-spheroid, kahverengi, 1.29 x 1.76 mm.
Çiçek açma zamanı: 5-8.
Habitat: Nemli, çalılık ve orman açıklıkları, 100-1550 m.
Endemizm durumu: Endemik değil
Fitocoğrafik bölgesi: Akdeniz elementi
Tehlike kategorisi: LC (Least Concern) Az tehdit altında
Polen tipi- şekli: Trikolporat - prolat (P/E:1.45), orta (P x E : 25.69 x 17.61 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları hafif sivri; clg: 16.78 µm, clt: 0.78 µm. Porlar; belirgin, plg: 5.97 µm, plt: 5.61 µm, plg/plt: 1.06, sferoid, Tektat - Faveolat, polar bölge psilat, ekzin : 0,91 µm (Şekil 3).



Şekil 3. *D. rectum'*a ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

Dorycnium graecum (L.) Ser. in DC, Prodr. 2:208 (1825).
Çok yıllık, otsu veya küçük yarı çalı formunda. Gövde, 25-90 cm uzunluğunda, kıvrık kaba sert tüylü. Yapraklar 5-7 parçalı ve 1-2.5 mm uzunluğunda rakisli. Yaprakçıklar obovat-oblong'tan oblanseolat'a kadar şekilli, 10-40 x 3-15 mm seyrek kısa yumuşak ve yatık uzun tüylü, mukronat. İnternodlar 1,5-8 cm. Çiçek kümesi şemsiye şeklinde hemen hemen kapitat, 7-47 çiçekli, pedonkül 1.5-7 cm. İnvolukrum brakteleri çok küçük, çiçek sayısından az ve uçları koyu pembe renkte. Pedisel kaliks tüpü ile aynı boyda veya biraz kısa, 1-2 mm. Kaliks; 2-4.5 mm uzunluğunda, ince uzun yumuşak tüylü, tüp düz bir şekilde 1-2 mm, pembemsi renkte, kaliks dişleri lanseolat-subulat şekilde, uzunluğu 1-2.5 mm. Çiçekler; beyaz renkte, 5-8 mm, veksillum 7-7.5 mm, ala 4 mm ve uçta birleşik değil, karina 4-4.5 mm. Ovaryum 4-5 mm, stilus yaklaşık 1 mm uzunluğunda. Legümen meyve; oblong-silidirik'ten hafifçe konik'e kadar şekilli, 4-10 x 1.5-3 mm, gaga 1-2 mm uzunluğunda, meyve olgunlaştığında açılmaz. Tohum; 1-4 adet, yüzey granular, şekli ovoid-orbikular, 2.29 x 1.89 mm.
Çiçek açma zamanı: 4-8.
Habitat: Kısmen nemli ve gölge yerler, yol kenarları, açık eğimli alanlar, maki, iğne yapraklı ve yaprak döken ormanlar, 1-2000 m.
Endemizm durumu: Endemik değil
Fitocoğrafik bölgesi: Öksin elementi
Tehlike kategorisi: LC (Least Concern) Az tehdit altında
Polen tipi- şekli: Trikolporat - prolat (P/E:1.52), orta (P x E : 27.07 x 17.77 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları sivri; clg: 17.44 µm, clt: 0.89 µm. Porlar; belirgin, plg: 6.10 µm, plt: 5.91 µm, plg/plt: 1.03, sferoid, tektat - Psilat, çok az faveolat, ekzin : 0,98 µm (Şekil 4).



Şekil 4. *D. graecum*'a ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

Dorycnium pentaphyllum Scop., Fl. Cam. ed. 2, 2:87 (1772).

Çok yıllık, otsu veya küçük yarı çalı formunda. Gövde, 17-65 cm uzunluğunda, yoğun yada değil parlak kısa ve yumuşak ve yarı yatık ve dik uzun yada kısa tüylü. Yapraklar 5 parçalı ve rakis yok. Yaprakçıklar oblong, oblanseolat, obovat yada linear, 6-20 x 1-5 mm, hemen hemen dik yayık ve yatık uzun yada kısa tüylü, akutdan mukronat-obtusa kadar uçlu. İnternodlar 1-6 cm. Çiçek kümesi şemsiye şeklinde hemen hemen kapitat, yoğun yada seyrek halde 3-35 çiçekli, pedonkül 1-6.5 cm. İnvolukrum brakteleri çok küçük, çiçek sayısından az ve uçları morumsu kırmızı renkte. Pedisel kaliks tüpü ile aynı boyda yada biraz uzun, 0.7-2.2 mm. Kaliks; 1.2-4.5 mm uzunluğunda, yoğun yada seyrek halde kısa yada uzun tüylü, tüp düz bir yapıda, 0.7-2.2 mm, saman sarısı yada hemen hemen pembemsi renkte, belirgin olmayan şeklide 2 dudaklı, üstteki 2 kaliks dişi alttaki diğer 3 dişten daha geniş, kaliks dişleri kısa üçgen veya sivri şekilde, uçları koyu yeşil yada morumsu kırmızı renkte, uzunluğu 0.3-2.2 mm. Çiçekler; beyaz renkte, 3-7 mm, veksillum 4-7 mm, ala 4-5.5 mm ve uçta birleşik, karina 3-5 mm, karina uçları morumsu kırmızı renkte. Ovaryum 2-4 mm, stilus geriye doğru hafifçe kıvrık ve 0.5 mm uzunluğunda. Legümen meyve, ovoid globular, 2-8 x 1-3.5 mm, gaga 1-2.2 mm uzunluğunda, meyve olgunlaştığında açılmaz. Tohum; 1 adet, yüzey basit retikulat, hafif düz ve tüberkülat, şekli reniform ya da oblong, yeşil renkte, 1.19-2.31 x 1.39-1.93 mm.

1. Çiçek kümeleri 15-35 çiçekli, çiçekler 3-5 mm, kaliks dişlerinin boyu kaliks tüpünün uzunluğundan kısa, yaprakçıklar oblong-ovat, 6-17x2-4 mm, bitki kısa-yumuşak,dik yatık ve kıvrık tüylü... **ssp. *herbaceum***
1. Çiçek kümeleri 3-17 çiçekli, çiçekler 3-7 mm, kaliks dişlerinin boyu kaliks tüpünün uzunluğu kadar, yaprakçıklar oblong, linear- oblanseolat şekilli ve 6-20 x 1-5.5 mm, bitki yoğun parlak ve yumuşak, yatık, uzun yada kısa tüylü.
    2. Bitki, 20-47 cm, yoğun yumuşak ve yarı yatık ve dik uzun tüylü, yaprakçıklar oblong-oblanseolat, 6-18 x 1-4 mm……..**ssp. *anatolicum***
    2. Bitki, 20-65 cm, yoğun halde parlak yumuşak ve yatık kısa tüylü, Yaprakçıklar linear-oblanseolat, 8-20 x 1.5-5 mm……**ssp. *haussknechtii***

subsp. *herbaceum* (Vill.) Rouy in Rouy et Fouc, Fl. Fr. 5:135 (1899)

Çiçek açma zamanı: 5-8.

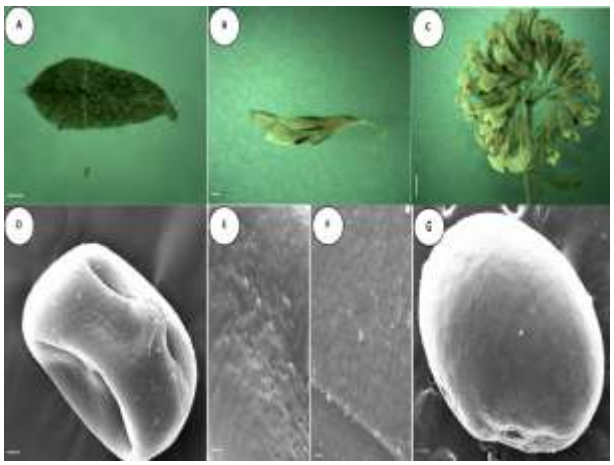
Habitat: Killi ve kireç taşlı topraklar, yol kenarları, yamaçlar, deniz kenarındaki eğimli alanlar, makilikler ve nemli alanlar, 1-1600 m.

Endemizm durumu: Endemik değil

Fitocoğrafik bölgesi: Akdeniz elementi

Tehlike kategorisi: LC (Least Concern) Az tehdit altında

Polen tipi- şekli: Trikolporat - prolat (P/E:1.46), orta (P x E : 26.72 x 18.19 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları sivri; clg: 18.22 µm, clt: 0.91 µm. Porlar; belirgin, plg: 6.38 µm, plt: 5.93 µm, plg/plt: 1.07, sferoid, Tektat – Faveolat, ekzin : 0,96 µm (Şekil 5).



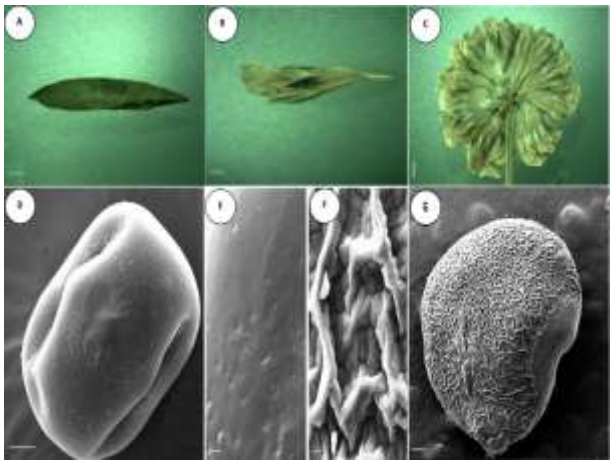
Şekil 5. *D. pentaphyllum* subsp. *herbaceum*'a ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

subsp. *anatolicum* (Boiss.) Gams in Hegi, III. Fl. Mittel-Eur. 4(3): 1378 (1923)

Çiçek açma zamanı: 5-7.

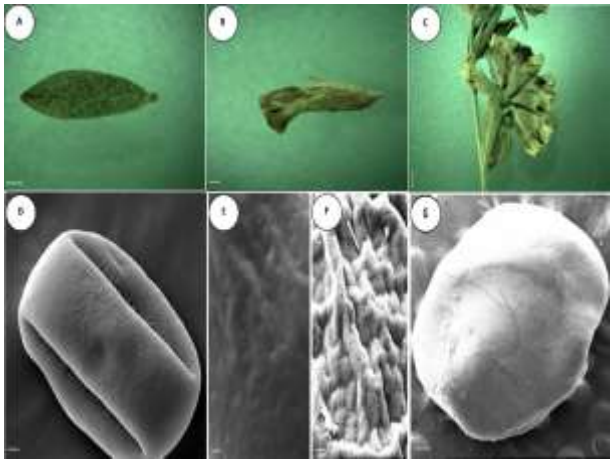
Habitat: Kireç taşlı stepler, kuru çayırlar, taşlı meralar, *Pinus brutia*, *Pinus nigra* ormanı ve *Quercus* çalılıkları, 100-1830 m.

Endemizm durumu: Endemik değil
Fitocoğrafik bölgesi: Akdeniz elementi
Tehlike kategorisi: LC (Least Concern) Az tehdit altında
Polen tipi- şekli: Trikolporat - prolat (P/E:1.34), orta (P x E : 27.16 x 20.25 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları hafifçe sivri; clg: 19.13 µm, clt: 1.19 µm. Porlar; belirgin, plg: 7.20 µm, plt: 5.80 µm, plg/plt: 1.24, subprolat, tektat – faveolat, ekzin : 0,95 µm (Şekil 6).



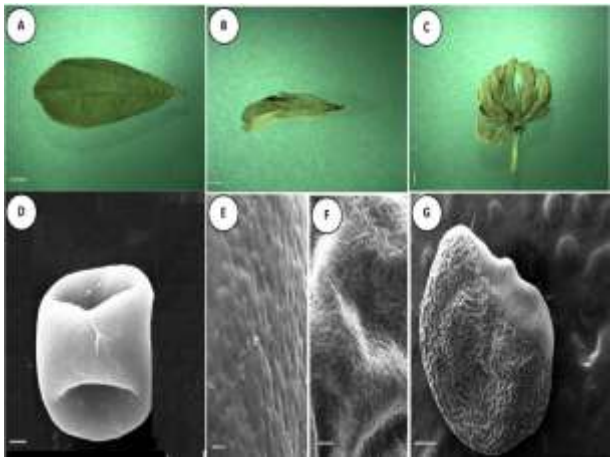
Şekil 6. *D. pentaphyllum* subsp. *anatolicum*'a ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

subsp. *haussknechtii* (Boiss.) Gams in Hegi, III. Fl. Mittel-Eur. 4(3): 1378 (1923).
Çiçek açma zamanı: 5-8.
Habitat: Kuru, kireç taşlı yamaçlar, *Quercus coccifera* makilikleri, konifer ormanları, özellikle *Pinus brutia* altları, 200-1650 m.
Endemizm durumu: Endemik
Fitocoğrafik bölgesi: İran-Turan elementi
Tehlike kategorisi: LC (Least Concern) Az tehdit altında
Polen tipi- şekli: Trikolporat - prolat (P/E:1.52), orta (P x E : 32.29 x 21.19 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları sivri; clg: 24.37 µm, clt: 0,85 µm. Porlar; belirgin, plg: 5.41 µm, plt: 6.17 µm, plg/plt: 0.87, suboblat, tektat – Faveolat, ekzin : 0,96 µm (Şekil 7).



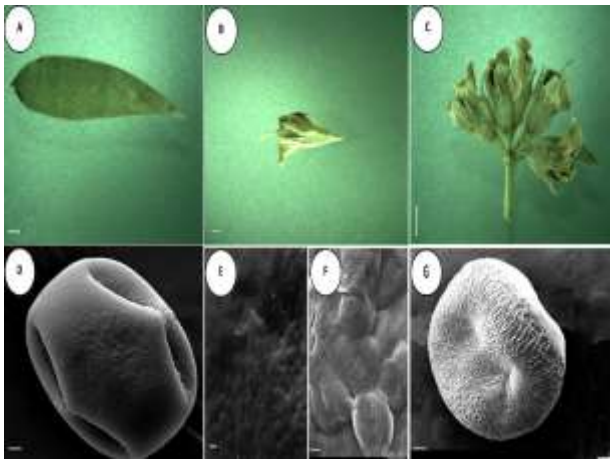
Şekil 7. *D. pentaphyllum* subsp. *haussknechtii*'ye ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

Dorycnium amani Zohary in Pal. J. Bot., Jer. Ser. 2:165, f. 16-18 (1941).
Çok yıllık, tabanda odunsu formda. Gövde, 25-45 cm uzunluğunda, seyrek kısa yatık tüylü. Yapraklar 5 parçalı ve 1.5-3 mm uzunluğunda rakisli. Yaprakçıklar kalın yapılı, obovat-oblong şekilde, 10-18 x 5-12 mm, seyrek kısa yatık tüylü, obtuz. İnternodlar 2.3-7.2 cm. Çiçek kümesi hemen hemen kapitat, 5-12 çiçekli, pedonkül 1.2-2 cm, yanlarda yer alan çiçek kümeleri daha kısa saplı 2-7 mm yada sapsız. İnvolukrum brakteleri çok küçük, çiçek sayısı kadar ve uçları morumsu kırmızı renkte. Pedisel çok kısa 0.4-0.8 mm. Kaliks; 3-4 mm uzunluğunda, seyrek kısa yatık tüylü, tüp düz bir şekilde 2-3 mm, sarımsı yeşil renkte, kaliks dişleri triangular-lanseolat, uzunluğu 1-2 mm. Çiçekler; beyaz veya parlak sarı-beyaz renkte, 3-4 mm, veksillum 3-4 mm, ala 4 mm ve uçta birleşik, karina 3-4 mm. Ovaryum 3-3.5 mm, stilus yaklaşık 1 mm uzunluğunda. Legümen meyve; ellipsoid, 5-6 x 3-4 mm, gaga 1-1.5 mm uzunluğunda, meyve olgunlaştığında açılmaz. Tohum; 1 adet, yüzey basit retikulat, şekli oblong, 1.79 x 1.43 mm.
Çiçek açma zamanı: 5-7.
Habitat: Kalkerli ve dik yamaçlar, *Quercus* açıklıkları, kuru tepeler, makilikler, 970- 1700 m.
Endemizm durumu: Endemik
Fitocoğrafik bölgesi: Doğu Akdeniz elementi
Tehlike kategorisi: CR (Critically Endangered) Kritik Tehlikede
Polen tipi- şekli: Trikolporat - prolat (P/E:1.42), küçük (P x E : 18.80 x 13.16 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları hafif sivri; clg: 11.59 µm, clt: 1,99 µm. Porlar; belirgin, plg: 5.08 µm, plt: 6.07 µm, plg/plt: 0.83, suboblat, tektat - Faveolat ve hafif rugulat, ekzin : 0,88 µm (Şekil 8).



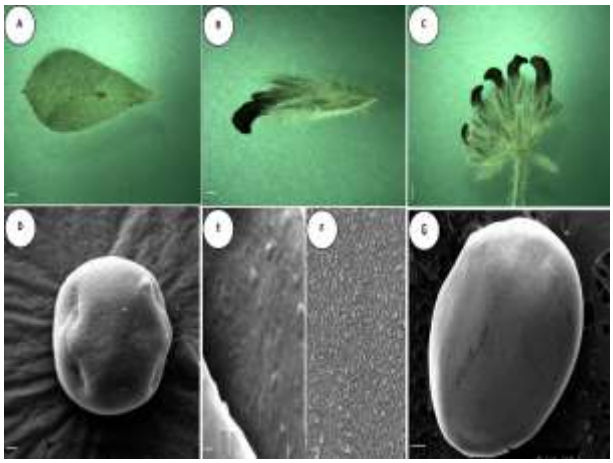
Şekil 8. *D. amani*'ye ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

Dorycnium axilliflorum Hub.-Mor. in Feddes Rep. 46:138, t. 270 (1939).
Çok yıllık, tabanda odunsu formda. Gövde, 10-25 cm uzunluğunda, parlak, seyrek kısa yatık tüylü. Yapraklar 5 parçalı ve rakis yok. Yaprakçıklar oblong-linear şekilde, 10-17 x 2-5 mm, kenarları biraz katlanmış halde, yapraklar parlak, yumuşak, yatık tüylü, akut. İnternodlar 1.6-4.3 cm. Çiçek kümesi her yaprak koltuğundan 2-3 tane çıkar ve her küme 2-15 çiçekli, pedonkül çok kısa 0.5-5 mm. İnvolukrum brakteleri çok küçük, çiçek sayısı kadar ve uçları morumsu kırmızı renkte. Pedisel neredeyse yok denecek kadar kısa. Kaliks; 2.5-3 mm uzunluğunda, parlak, yumuşak ve yatık tüylü, tüp düz bir şekilde 1.5-2 mm, kaliks dişleri triangular, uzunluğu tüp kadar yada kısa. Çiçekler; beyaz renkte, 4-5 mm, veksillum 4-5 mm, ala 4 mm ve uçta birleşik, karina 3-3.5 mm. Ovaryum 3-3.5 mm, stilus yaklaşık 1 mm uzunluğunda. Legümen meyve; elips, 4-6 x 2-5 mm, gaga uzunluğu 1.4-1.8 mm uzunluğunda, meyve olgunlaştığında açılmaz. Tohum; 1 adet, yüzey tüberkülat, şekli eliptik, 1.18 x 1.08 mm.
Çiçek açma zamanı: 5-6.
Habitat: *Quercus* çalılıklarındak kireçli topraklar ve *Pinus brutia* açıklıkları, 1200-1250 m.
Endemizm durumu: Endemik
Fitocoğrafik bölgesi: Doğu Akdeniz elementi
Tehlike kategorisi: EN (Endangered) Tehlikede
Polen tipi- şekli: Trikolporat - prolat (P/E:1.36), orta (P x E : 28.59 x 20.88 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları hafif sivri; clg: 24.51 µm, clt: 0,88 µm. Porlar; belirgin, plg: 5.57 µm, plt: 5.01 µm, plg/plt: 1.11, sferoid, tektat – Faveolat, ekzin : 0,96 µm (Şekil 9).



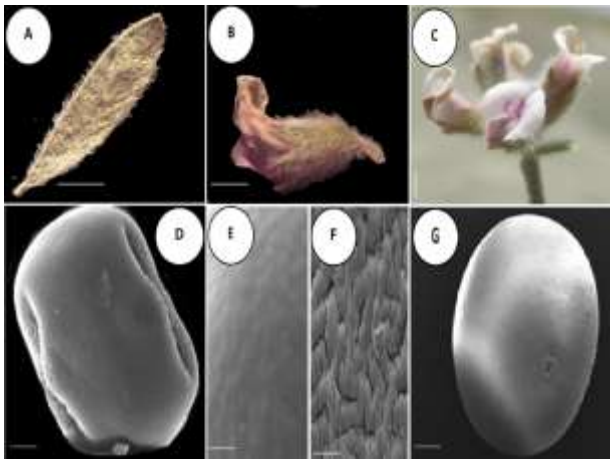
Şekil 9. *D. axilliflorum*'a ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

Dorycnium sanguineum Vural in Notes R.B.G. Edinb. 41:69, t. 2 & 3 (1983).
Çok yıllık, tabanda odunsu formda. Gövde, 20-25 cm uzunluğunda, beyaz ince uzun yumuşak tüylü. Yapraklar 5 parçalı ve rakis 1-4 mm. Yaprakçıklar obovat-eliptikden eliptiğe kadar şekilde, 5-20 x 3-10 mm, yapraklar yoğun şekilde ince uzun yumuşak tüylü, mukronat. İnternodlar 1-3 cm. Çiçek kümesi şemsiye şeklinde hemen hemen kapitat 4-8 çiçekli, pedonkül 0.5-2 cm. İnvolukrum brakteleri çiçeklerle eşit sayıda, yeşil renkte, mızraksı şeklide ve 2.5-4 mm uzunluğunda. Pedisel yok yada çok kısa 1 mm. Kaliks; 4.5-5 mm uzunluğunda, beyaz uzun ince yumuşak tüylü, tüp hemen hemen kıvrılmış ve taban kısmı hafifçe kambursu yapıda, 1.5-2 mm, saman sarısı ile parlak pembe renkli, kaliks dişleri dar triangular-mızraksı, uzunluğu tüp kadar yada çok az uzun 1-5-2.1 mm, diş uçları siyaha yakın morumsu kırmızı. Çiçekler; kan kırmızısı renkte, 5-7 mm, veksillum 5-7 mm, belirgin şekilde geriye doğru kıvrık, ala 5 mm ve uçta birleşik, karina 4 mm. Ovaryum 2.5-3 mm ve yoğun ince uzun ve yumuşak tüylü, stilus yaklaşık 1 mm uzunluğunda. Legümen meyve; ovoid, 5-5.5 x 2.5-3 mm, taban kısmı hariç sert kaba tüylü, gaga uzunluğu 1.5 mm, meyve olgunlaştığında açılmaz. Tohum; 1-2 adet, yüzey basit retikulat, şekli oblong, 2.56 x 2.00 mm.
Çiçek açma zamanı: 5-7.
Habitat: *Pinus brutia* ormanı açıklıları ve kireçli topraklar, 550-600 m.
Endemizm durumu: Endemik
Fitocoğrafik bölgesi: Doğu Akdeniz elementi
Tehlike kategorisi: EN (Endangered) Tehlikede
Polen tipi- şekli: Trikolporat - prolat (P/E:1.21), küçük (P x E : 20.77 x 17.06 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları hafif sivri; clg: 12.81 µm, clt: 0,89 µm. Porlar; belirgin, plg: 6.85 µm, plt: 5.68 µm, plg/plt: 1.20, subprolat, tektat - Psilat, çok az faveolat, ekzin : 0,86 µm (Şekil 10).



Şekil 10. *D. sanguineum*'a ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 1 mm; D: 2 µm; E: 1 µm, F: 10 µm; G: 100 µm.

Dorycnium vuralii Karaman, B.Şahin & Aytaç in Turkish Journal of Botany 48:2 (2024)
Çok yıllık, yarı çalımsı. Gövde, dik yapıda, 10-25 cm uzunluğunda, dik-yatık dallı, yoğun yatık-yükselici ipeksi tüylü. Yapraklar, sapsız, 5 parçalı, rakis 2-5 mm. Yaprakçıklar ters yumurtamsı-dikdörtgensi şekilde, 3-17 x 1-6 mm, yapraklar uzun yayık-yatık tüylü, mukronat. İnternodlar 1-2 cm. Çiçek kümesi belirsizce top başlı şemsiye şeklinde, 3-6 çiçekli, pedonkül 1-1.4 cm. Brakte 1.5-4 mm. Pediseller yatık ipeksi tüylü, 8-16 mm. Uzunluğunda. Kaliks; 4-5 mm uzunluğunda, ince ve kısayatık tüylü, yeşil renkli, dişler üçgensi, eşit uzunlukta, sivri uçlu, tüpten belirsizce kısa ve 1.5-2 mm. Çiçekler; beyaz-pembe renkte, 4-5 mm, bayrakçık beyaz renkli pembe çizgili, 4-5 mm, yumurtamsı, küt uçlu, tüysüz. Kanatçık beyaz renkli pembe çizgili 3.5-4 mm ve uçta birleşik, kayıkçık pembe renkli 3.5-4 mm. Ovaryum 1.5-2 mm, stilus yaklaşık 2 mm uzunluğunda, tüysüz. Legümen meyve; yumurtamsı-dikdörtgensi şekilde, 5-7 x 2-3 mm, tüysüz, gaga uzunluğu 1.5-2 mm, meyve olgunlaştığında açılır. Tohum; 1, yüzey benekli veya beneksiz, şekli dikdörtgensi-böbreksi, 2-3 x 1-2 mm.
Çiçek açma zamanı: 5-6.
Habitat: *Marnlı* ve kireçli topraklar, 800-900 m.
Endemizm durumu: Endemik
Fitocoğrafik bölgesi: İran-Turan elementi
Tehlike kategorisi: CR (Critically Endangered) Kritik Tehlikede
Polen tipi- şekli: Trikolporat - prolat (P/E:1.01) , küçük (P x E : 22.72 x 22.41 µm), kolpuslar; ince, uzun, sınırları belirgin, uçları hafif sivri; clg: 14.93 µm, clt: 3.45 µm. Porlar; belirgin, plg: 7.43 µm, plt: 6.73 µm, plg/plt: 1.09, prolat–spheroidal, psilate–perforate, ekzin : 0.69 µm (Şekil 11).



Şekil 11. *D. vuralii*'ye ait morfolojik yapılar, A) Yaprak, B) Çiçek, C) Çiçek kümesi; polen ve tohum SEM fotoğrafları, D) Polen, E) Polen yüzey, F) Tohum yüzey, G) Tohum. Ölçek çizgileri: A, B, C: 2 mm; D: 10 µm; E: 2 µm, F: 500 µm; G: 10 µm, © Şahin ve ark., 2024'dan alınmıştır.

Bu çalışmada, Fabaceae familyasına ait Türkiye'de doğal olarak yayılış gösteren *Dorycnium* cinsinin sistematik yönden revizyonu; doğal ortamlarından ve farklı lokalitelerden toplanan bitki örnekleri üzerinde uygulanan morfolojik ve palinolojik incelemeler ile yapılmıştır.
Dorycnium cinsi dünya üzerinde 13 tür ile temsil edilirken, Türkiye'de 12 takson (8 tür, 3 alt tür ve 1 varyete) ile temsil edilmekte olup endemik takson sayısı 5'tir.

Dorycnium taksonlarının Türkiye'deki yayılışına baktığımızda; *D.hirsutum*'un, Ege, Marmara ve Doğu Akdeniz bölgelerinin kıyıya yakın noktalarında genellikle yükseltisi az, sıcaklık ve nem seviyesi fazla olan vejetasyonlarda yayılış gösterirken, *D. hirsutum* var. *syriacum*'un sadece Hatay ilinde denize kıyı dar bir alanda lokalize olduğu görülmüştür. *D. rectum* türü de Akdeniz ve Marmara bölgelerinde denize yakın noktalarda ancak farklı yüksekliklerde yetişmektedir. *D. graecum* türü Doğu Akdeniz, İç Anadolu ve Ege'nin kuzeyi ile Marmara ve Batı Karadeniz de yoğun olmak üzere Karadeniz bölgesinde farklı yüksekliklerde ve fakat kısmen nemli, ılıman yerleri tercih etmektedir. *D. pentaphyllum* subsp. *herbaceum* kısmen iç bölgeler olsa da genellikle Anadolunun kuzey bölgelerinde dağılış gösterirken, *D. pentaphyllum* subsp. *anatolicum* iç bölgelerde, *D. pentaphyllum* subsp. *haussknechtii* ise Doğu Akdeniz'de yayılış göstermektedir. *D. amani* Hatay Amanoslarda lokalize olmuşken, *D. axilliflorum* sadece Burdur ilinde, *D. sanguineum* Karaman'da, *D. vuralii* ise Çankırı'da dar bir alanda bulunmaktadır. *D. hirsutum* için B2 karesi, *D. rectum* için C2 ve C4 kareleri, *D. graecum* için B4 ve B6 kareleri, *D. pentaphyllum* subsp. *herbaceum* için B3, B6 ve C3 kareleri, *D. pentaphyllum* subsp. *anatolicum* için A2 ve A4 kareleri, *D. pentaphyllum* subsp. *haussknechtii* için B6 karesi yeni kayıt lokaliteleridir. Cinsin tür seviyesindeki endemizm oranı % 43, alt tür ve varyete seviyesinde ise % 25'tir (Çizelge 1).

Bu revizyon çalışması ile tespit edilen taksonlardan 4'ü Akdeniz, 4'ü Doğu Akdeniz, 2'i İran-Turan, 1'i Öksin fitocoğrafik bölgelerine ait elementleridir. Flora'da fitocoğrafik durumları belirtilmeyen taksonların habitatları ve lokaliteleri göz önüne alınarak yapılan değerlendirme neticesinde; *D. hirsutum* var. *syriacum* ve *D.amani* için Doğu Akdeniz, *D. pentaphyllum* subsp*. herbaceum* ve *D. pentaphyllum* subsp*. anatolicum* için ise Akdeniz fitocoğrafik bölgeleri önerilmiştir. *Dorycnium* cinsine ait tür ve tür altı kategorilerin tehlike düzeyleri 2021 IUCN kriterlerine göre belirlenerek verilmiştir. Ekim ve ark., (2000) sadece endemik türler (*D.amani*, *D. axilliflorum, D. pentaphyllum* subsp*. haussknechtii ve D. sanguineum*) için tehlike kategorisi tanımlamışlardır. Yaptığımız çalışma sonucunda tüm taksonların tehlike kategorisi; lokalite, populasyon ve birey sayısı, habitattaki biyotik ve abiyotik unsurlar, tür devamlılığını etkileyen biyolojik yapıya göre ayrıca belirlenmiştir.

Çizelge 1. *Dorycnium* cinsine ait türlerin dağılım, endemizm ve yükselti durumları (Grid sistemdeki yerler Davis (1970)'e göre belirlenmiştir)

Türler	**Toplayıcı No**	**Grid Sistem**	**Endemizm**	**Yükselti (m.)**
D. hirsutum var. *hirsutum*	YZK 885	A1, A2, B1, B2, C1, C2, C3, C5, C6	----	1- 900
D. hirsutum var. *syriacum*	YZK 883	C6	----	1-200
D. rectum	YZK 950	A2, C2, C4, C5, C6	----	100-1550
D. graecum	YZK 935	A1, A2, A3, A4, A5, A6, A7, A8, B1, B2, B3, B4, B5, B6, C5, C6	----	1-2000
D. pentaphyllum subsp*. herbaceum*	YZK 927	A1, A2, A3, A4, A5, A6, A7, A8, A9, B1, B2, B3, B6, B7, C2, C3	----	1-1600
D. pentaphyllum subsp*. anatolicum*	YZK 939	A2, A3, A4, A5, A6, B2, B3, B5, B6, B7, C2, C4, C5, C6	----	100-1830
D. pentaphyllum subsp*. haussknechtii*	YZK 916	B6, C3, C4, C5, C6, C9	Endemik	200-1650
D.amani	YZK 904	C6	Endemik	970-1700
D. axilliflorum	YZK 941	C2	Endemik	1200-1250
D. sanguineum	YZK 914	C4	Endemik	550-600
D. vuralii	B.Şahin 8151	A4	Endemik	800-900

Çalışılan türlerin tümü çok yıllık, yarı çalı formunda olup, *D. amani*, *D. axilliflorum* ve *D. sanguineum* türleri tabanda odunsu yapıya sahiptirler. Tüm türler çok gövdeli olup tabandan itibaren dalanma gösterirler dik-yükselici yapıdadırlar. *D. sanguineum* türünde steril gövdelere rastlanır. Yapraklar genellikle 5-7 parçalı olup, *D. vuralii* türünde 3-5 parçalıdır. *D. pentaphyllum* alt türleri ile *D. axilliflorum* dışında hepsi rakis taşırlar en uzun rakis yapısı (3-11 mm) *D. rectum* türünde görülür. Yapraklar oblong, obovat, lanseolat, linear ya da oblanseolat yapılarda ve genellikle seyrek ya da yoğun tüylüdürler. Yaprak ve gövdesinde göze çarpan şekilde yoğun tüy taşıyan *D. sanguineum* iken onu *D. hirsutum* ve *D. vuralii* türleri takip eder.

Çiçekler genellikle kapitat ya da subkapitat şemsiye şeklindedir. Cinsin sistematik açıdan iki seksiyona ayrılmasında en önemli ayırt edici karakter kaliks dişlerinin yapısıdır, bir tür eğer eşit 5 dişe sahip kaliksi var ise Bonjeania seksiyonuna, iki tanesi diğer üçüne göre daha geniş kaliks dişlerine sahip ise Dorycnium (Eudorycnium) seksiyonuna dâhil edilir. Korolla rengi genellikle beyaz ya da pembe iken *D. sanguineum* çok ayırt edilici şekilde kırmızı, *D. amani* ise parlak sarı yada beyaz renge sahiptir. Meyve genellikle legümen tipinde olup, oblong-silindirik ya da ovoid-globular yapıdadır ve tohum sayısı seksiyonları ayırt etmede önemli bir karakterdir, Bonjeania seksiyonuna dahil türler 1-7 adet tohuma sahipken, *Dorycnium* (Eudorycnium) seksiyonu içinde değerledirilen türler genellikle 1 tohuma sahiptir.

Cinsin polenleri trikolporat tipte ve prolat ile subprolat şekilde olup ornemantasyon genellikle tektat–faveolat olup, *D. vuralii*'de psilat–perforat yapıdadır. Cinsin polenleri PxE= 20.77-32.29 x 13.16-21.33 µm boyutlarındadır. P/E oranı en az olan tür *D. vuralii* (1.01) iken en çok olan tür *D. graecum* ve *D. pentaphyllum* subsp. *haussknechtii* (1.52) türleridir. Kolpuslar genellikle tüm türlerde ince uzun, sınırları belirgin, uçları sivridir.

Tüm türlerde porlar belirgin bir yapıdadır, en belirgin por yapısı ise *D. pentaphyllum* subsp. *anatolicum* türünde görülür. En kalın ekzin zar yapısı *D. hirsutum* (1.10 µm)'da görülmektedir (Çizelge 3).

Dorycnium cinsi türlerine ait tohumların incelenmesi sonucunda farklı büyüklük ve şekillerde oldukları görülmüştür. En büyük tohum *D. sanguineum* (2.56 x 2 mm) türünde görülürken, en küçük tohuma *D. hirsutum* (1.05 x 1.63 mm) türünde rastlanmıştır. Tohumlar boy-en oranı açısından değerlendirildiğinde en büyük orana *D. vuralii* (1.66), en küçük orana ise *D. hirsutum* (0.64) sahiptir. Türlerin çoğunluğunda hiluma yakın alanların tipik şekilde düz bir yapıda olduğu görülmüştür. Genellikle retikulat yapıdaki yüzey görünümü *D. graecum* türünde granular, *D. pentaphyllum* subsp. *herbaceum* türünde hafif tüberkülat, *D. pentaphyllum* subsp. *herbaceum* türünde multi-retikulat ve *D. axilliflorum* türünde ise tuberkulat yapıdadır (Çizelge 2).

D.hirsutum türü farklı habitatlarda yayılış gösterir ve sistematik olarak önemli bir karakter olan yoğun bir tüy yapısına sahiptir. Davis (1970) türün betiminden sonra belirttiği dipnotta Hatay'da yayılış gösteren ve tüy yapısının daha seyrek oluşu ve meyve boyunun kalikse eşit olduğu *D. hirsutum* var. *syriacum*'un varlığından bahsetmiş ancak örnek yetersizliği nedeniyle bu ifadesine kesinlik kazandıramamıştır. Bu duruma açıklık getirmek amacıyla yapılan arazi çalışmaları ile *D. hirsutum* var. *syriacum*'un Türkiye florası için yeni kayıt olduğu bu çalışma sonucu belirlenmiştir.

Bu çalışma sonucunda *Dorycnium* taksonlarına ait morfolojik bilgiler güncellenmiş daha önce belirlenmeyen karakterlere ait veriler de ayrıca belirtilmiş ve böylece türlerin betimlerine ait eksiklikler giderilmiştir.

Çizelge 2. *Dorycnium* Miller. cinsi türlerinin tohumlarına ait morfolojik ölçümler

Türler	**Büyüklük (mm)**	**Boy-En Oranı**	**Genel Şekli**	**Yüzey Şekli**
D. hirsutum var. *hirsutum*	1.05 x 1.63	0.64	Oblong-Reniform	Retikulat ve Düz
D. hirsutum var. s*yriacum*	1.50 x 1.33	1.12	Oblong	Retikulat ve Düz
D. rectum	1.29 x 1.76	0.73	Oblong-Sferoid	Basit Retikulat
D. graecum	2.29 x 1.89	1.21	Ovoid-Orbikular	Granular
D. pentaphyllum subsp. *herbaceum*	1.92 x 1.39	1.38	Oblong	Hafif tüberkülat ve Düz
D. pentaphyllum subsp. *anatolicum*	1.19 x 1.58	0.75	Reniform	Basit Retikulat
D. pentaphyllum subsp. *hausknechtii*	2.31 x 1.93	1,19	Oblong	Basit Retikulat
D. amani	1.79 x 1.43	1.25	Oblong	Basit Retikulat
D. axilliflorum	1.18 x 1.08	1.09	Eliptik	Tuberkulat
D. sanguineum	2.56 x 2.00	1.28	Oblong	Basit Retikulat
D. vuralii	2.5 x 1.5	1.66	Oblong	Retikulat ve Düz

Çizelge 3. *Dorycnium* cinsi taksonlarının polenlerine ait morfolojik ölçümler

Türler	P	E	P/E	Clg	Clt	Plg	Plt	Plg/Plt	Ekz
D. hirsutum var. *hirsutum*	28.72±1.78	20.87±1.07	1.37	20.70±1.46	0.76±0.26	4.70±0.79	4.55±0.73	1.03	1.10±0.28
D. hirsutum var. *syriacum*	31.52±1.03	21.33±1.15	1.47	21.83±1.46	0.72±0.29	5.33±1.02	5.16±0.91	1.03	0.98±0.15
D. rectum	25.69±1.40	17.61±1.26	1.45	16.78±1.03	0.78±0.23	5.97±0.65	5.61±0.73	1.06	0.91±0.19
D. graecum	27.07±1.17	17.77±1.18	1.52	17.44±1.23	0.89±0.19	6.10±0.53	5.91±0.84	1.03	0.98±0.18
D. pentaphyllum subsp. *herbaceum*	26.72±1.10	18.19±1.05	1.46	18.22±1.01	0.91±0.29	6.38±1.28	5.93±1.28	1.07	0.96±0.17
D. pentaphyllum subsp. *anatolicum*	27.16±1.76	20.25±1.78	1.34	19.13±0.94	1.19±0.46	7.20±1.03	5.80±0.79	1.24	0.95±0.14
D. pentaphyllum subsp.*hausknechtii*	32.29±1.20	21.19±1.19	1.52	24.37±1.03	0.85±0.18	5.41±0.86	6.17±0.69	0.87	0.96±0.17
D. amani	18.80±1.11	13.16±0.77	1.42	11.59±1.11	1.99±0.65	5.08±0.95	6.07±0.91	0.83	0.88±0.15
D. axilliflorum	28.59±1.97	20.88±0.78	1.36	24.51±0.77	0.88±0.36	5.57±0.18	5.01±0.13	1.11	0.96±0.20
D. sanguineum	20.77±1.37	17.06±0.78	1.21	12.81±1.16	0.89±0.16	6.85±0.93	5.68±0.99	1.20	0.86±0.11
D. vuralii	22.72±0.93	22.41±1.03	1.01	14.93±1.15	3.45±0.44	7.43±0.77	6.73± 1.08	1.09	0.69 ± 0.07

(P: Polar eksen, E: Ekvatoral eksen, Clg: Kolpus uzunluğu, Clt: Kolpus genişliği, Plg: Por uzunluğu, Plt: Por genişliği, Ekz: Ekzin zar kalınlığı)

SONUÇ ve ÖNERİLER

Türkiye'deki *Dorycnium* Miller. cinsinin revizyonu çalışması kapsamında doğal ortamlarından toplanan bu cinse ait örnekler üzerinde ayrıntılı şekilde yapılan morfolojik ve palinolojik analiz çalışmaları ile cinsin tür teşhis anahtarı düzenlenerek yenilenmiştir. Doğal ortamlarından toplanan cinse ait taksonlar üzerinde yapılan morfolojik incelemeler ile Türkiye Florası'nda (Davis, 1970,1988) belirtilen deskripsiyonlar genişletilmiş ve dipnot olarak belirtilen problemler de tespit edilerek çözüme kavuşturulmuştur. Türkiye Florası'nda *Dorycnium* cinsi; Bonjeania ve Dorycnium (Eudorycnium) olmak üzere iki seksiyona dâhil 6 tür, 3 alt tür ile değerlendirmiştir (Davis, 1970). Daha sonra tanımlanan yeni türler ile takson sayısı 11' e ulaşmıştır ulaşmıştır (Vural, 1983; Şahin ve ark., 2024). Davis'in Flora of Turkey'de *D. hirsutum* için dipnot olarak belirttiği ancak yeterli örneklerle desteklenmediği için varlığı ispat edilemeyen *D. hirsutum* var. *syriacum*'un bu çalışma sonucunda Türkiye'de yayılış gösterdiği tespit edilmiştir (Davis, 1970). Bu çalışmanın sonucuna göre; *Dorycnium* cinsi Türkiye'de 8 tür, 3 alt tür ve 1 varyete ile temsil edilmekte olup endemik takson sayısı 5 tanedir. Cinsin tür seviyesindeki endemizm oranı % 40, alt tür ve varyete seviyesinde ise % 25'tir.

Taksonlara ait polen tipi ve şekli genel olarak trikolporat – prolat yapıda iken *D. sanguineum*'da trikolporat – subprolat'tır. Taksonların tohum şekli genel olarak; oblong, reniform veya eliptik olup en büyük tohuma *D. vuralii*'de (2.56 x 2.00 mm) rastlanır (Şahin ve ark., 2024). Tohum yüzeyi genellikle düz veya retikulat yapıdadır.

Türkiye zengin biyoçeşitliliğe sahiptir, floristik ve taksonomik çalışmalar bu eşsiz yapıyı ortaya çıkarırken bir yandan da bu doğal hazinenin korunarak gelecek kuşaklara aktarılması açısından önem arz eder. Sistematik çalışmalar sonucu tür bazında belirlenen morfolojik ve ekolojik özellikler sayesinde, bu türlerin farklı bilimsel alanlarda değerlendirilmesine imkân sağlanmış olur.

Not

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Makale yazarları aralarında herhangi bir çıkar çatışması olmadığını beyan ederler.

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Original Articled

Antagonists for the Control of *Botrytis cinerea* in Tomatoes: An *In Vitro* Evaluation and *In Silico* Screening By Molecular Docking of Possible Inhibitors

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ABSTRACT

This study was conducted to investigate the antifungal effects of candidate antagonists *Clonostachys rosea*, *Trichoderma harzianum*, and *Bacillus mojavensis* against *Botrytis cinerea* pathogen and to examine their interactions under *in vitro* conditions and *in silico* examine by molecular docking. The effects of candidate antagonist applications on the mycelial growth of *B. cinerea* M2-1 isolate showed that the most effective isolate was *T. harzianum* C7-3 (56%) followed by *B. mojavensis* K193 (32%) and *C. rosea* C6-4 (26%). When evaluating the interactions between the candidate antagonist isolates, it was determined that *T. harzianum* and *B. mojavensis* reduced the mycelial growth of *C. rosea* compared to the control. In the *T. harzianum* × *B. mojavensis* combination, the fungal antagonist's mycelial growth was inhibited when in contact with the bacterial isolate. Additionally, the effects of candidate antagonists on the root and shoot length of tomato seeds (cv. Super) were measured, and germination percentages were calculated. *Clonostachys rosea* (3.09 cm) and *B. mojavensis* (3.57 cm) promoted root development, while *B. mojavensis* K193 (4.02 cm) enhanced shoot development, and *T. harzianum* C7-3 improved seed germination percentage (86.7%) compared to the control. The molecular docking findings demonstrated that the combination of ligands from *T. harzianum* could synergistically enhance antifungal efficacy against *B. cinerea* by inhibiting or modifying proteins associated with pathogenicity and virulence. Result of *in silico* study highlighted the necessity for more laboratory research to validate the impact of *T. harzianum*-derived metabolites on the proteins of *B. cinerea* and their interactions.

Key words: Gray mold disease, *Clonostachys rosea*, *Trichoderma harzianum*, *Bacillus mojavensis*, molecular docking

Domateste *Botrytis cinerea*'nın Kontrolünde Antagonistler: Olası İnhibitörlerin Moleküler Bağlanma Üzerine *İn Vitro* Değerlendirme ve *İn Silico* Tarama

Bu çalışma, *Botrytis cinerea* patojenine karşı *Clonostachys rosea*, *Trichoderma harzianum* ve *Bacillus mojavensis* aday antagonistlerinin antifungal etkilerini ve aday antagonistlerin karşılıklı etkileşimlerini, moleküler bağlanma analiziyle de *in vitro* ve *in silico* etkileşimlerini incelemek amacıyla yürütülmüştür. Çalışmada aday antagonist uygulamalarının *B. cinerea* M2-1 izolatının misel gelişimi üzerine etkilerine bakıldığında %56 oranı ile en etkili izolatın *T. harzianum* C7-3 olduğu, bu izolatı %32 oranı ile *B. mojavensis* K193 ve %26 oranı ile *C. rosea* C6-4 izolatlarının takip ettiği belirlenmiştir. Aday antagonist izolatlarının karşılıklı etkileşimleri değerlendirildiğinde *T. harzianum* ve *B. mojavensis*'in *C. rosea*'nın misel gelişimini kontrole oranla azalttığı belirlenmiştir. *Trichoderma harzianum* × *B. mojavensis* eşleştirilmesinde fungal antagonistin misel gelişimi bakteriyel izolat ile karşılaştıkları hatta bakteriyel izolat tarafından engellenmiştir. Çalışmada ayrıca aday antagonistlerin domates tohumlarının (cv. Süper) kök ve sürgün uzunluğuna ve çimlenme yüzdesi üzerine etkisi araştırılmıştır. *Clonostachys rosea* (3.09 cm) ve *B. mojavensis* (3.57 cm) izolatları tohumların kök gelişimlerini, *B. mojavensis* K193 izolatı (4.02 cm) tohumların sürgün gelişimini ve *T. harzianum* C7-3 izolatı ise tohumların

çimlenme yüzdesini (%86.7) kontrole oranla artırmıştır. Moleküler bağlanma bulguları, *T. harzianum*'dan elde edilen ligandların kombinasyonunun, patojenisite ve virülanslıkla ilişkili proteinleri inhibe veya modifiye ederek *B. cinerea*'ya karşı antifungal etkinliği sinerjik bir şekilde artırabileceğini göstermiştir. *In silico* çalışma sonuçları, *T. harzianum* kaynaklı metabolitlerin *B. cinerea* proteinleri üzerindeki etkilerini ve etkileşimlerini doğrulamak için daha fazla laboratuvar araştırmasına ihtiyaç olduğunu göstermiştir.

Anahtar kelimeler: Gri küf hastalığı, *Clonostachys rosea*, *Trichoderma harzianum*, *Bacillus mojavensis*, moleküler bağlanma

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the important sources of income for producers (Vural et al., 2000). This vegetable is an important antioxidant against various cancers and neurological diseases with rich in vitamins and minerals (Srinivasan, 2010). The suitability of Türkiye's climatic conditions for tomato cultivation and the rapid establishment of processing industries since the 1970s have increased interest in tomato farming (Gelmez and Müftüoğlu, 2018). Türkiye ranks as the world's third-largest producer of tomato, with an annual production of 13 million tons, following India (20 million tons) and China (68 million tons), establishing its position as a key global producer (FAO, 2022).

Botrytis cinerea Pers. ex Fr. (teleomorph: *Botryotinia fuckeliana* (de Bary) Whetzel) is one of the most studied necrotrophic plant pathogens responsible for gray mold disease in tomato, and has been reported on over 1,400 monocotyledons and dicotyledons plant species (Mouekouba et al., 2014; Elad, 2016; Hammad et al., 2021). This pathogen ranks among the top 10 plant pathogens causing disease (Dean et al., 2012), and responsible for annual losses ranging from 10 to 100 billion dollars (Boddy, 2016). Effective control strategies of *B. cinerea* include cultural (Elad et al., 2016), chemical (Mamiev et al., 2022), and biological (Guzmán-Guzmán et al., 2023). While fungicides are commonly used in the control of this pathogen (Hahn, 2014), the known disadvantages of fungicides have led to an increased focus on biological control method (Guzmán-Guzmán et al., 2023). Research has demonstrated that antagonistic fungi and bacteria possess strong activity and considerable potential for the biological control of *B. cinerea* in tomatoes (Mónaco et al., 2009; Geng et al., 2022; Kesimci and Dönmez 2022; Zheng et al., 2023). Among fungal antagonists, *Clonostachys rosea* is a saprophytic fungus belonging to the Ascomycota phylum. This species is commonly found in soil and many different habitats, and distributed globally. *Clonostachys rosea* is an excellent mycoparasite, and demonstrates strong biological control effect against numerous fungal plant pathogens, nematodes, and insects (Sun et al., 2020). Similarly, *Trichoderma* spp., which also belong to the Ascomycota phylum, are among the most successful biocontrol agents (BCAs). Within the global biological control market, 50-60% is based on these species (Verma et al., 2007; Guzmán-Guzmán et al., 2023). Furthermore, there is an increasing number of new *Trichoderma*-based products that are regularly registered and many biopesticide companies regularly approve these products, as their field application/trials are widely accepted (Verma et al., 2007). Similarly, recent studies on the biocontrol of *B. cinerea* using bacterial antagonist have particularly focused on *Bacillus* (Poveda et al., 2020; Amarouchi et al., 2021; Bolivar-Anillo et al., 2021; Roca-Couso et al., 2021). *Bacillus* species are considered biologically safe and are widely used in agriculture (Toral et al., 2018). These species are found in soil, water, and air, and typically exert their effects against phytopathogens by producing various antifungal and antimicrobial compounds (Zheng et al., 2023). Furthermore, members of the *Bacillus* spp. are considered effective BCAs due to their potential to colonize plant roots, promote plant growth, and induce systemic resistance mechanisms in plants (Alina et al., 2015). To date, isolates of *Trichoderma harzianum*, *T. viride*, *T. hamatum*, *T. asperellum*, *C. rosea*, *C. rosea* f. *catenulata*, *C. rosea* f. *rosea*, and *Bacillus* spp. isolates have been shown to effectively control *B. cinerea* in various studies (Eken et al., 2013; Hammad et al., 2021; Risoli et al., 2022; Zheng et al., 2023). In addition, there are numerous preparations obtained from various antagonists available on the market that have been successful in biological control studies. However, recent studies have continuously tested different isolates of the same species, with efforts being made to develop new preparations. This situation highlights the special and important nature of biocontrol studies (Yıldız and Özyılmaz, 2023).

BCAs can synthesize secondary metabolites with different structures that have disease-suppressive biological action (Lahlali et al., 2022). Examples include alkaloids, phenols, lignans, quinones, peptides, steroids, and lipids (Khalil et al., 2021; Rahila et al., 2023). BCAs offer development and protection to the host plant, making them healthier (Grabka et al., 2022). These agents hydrolytic enzymes break down pathogen cell walls, and their phyto hormones help plants grow and respond to stress (Singh et al., 2017). Systemic resistance in plants is induced by plant growth promoters' production of antimicrobials and volatile organic molecules (Enebe and Babalola, 2019). *Botrytis cinerea* utilizes various mechanisms to colonize host tissue and establish infection.

These include the secretion of phytotoxic compounds, cell wall-degrading enzymes, and cell death-inducing proteins (CDIPs), which contribute to disease progression and host tissue necrosis (Zhang et al., 2021). CDIPs are known to trigger a hypersensitive response in host plants, mimicking programmed cell death mechanisms. Among these, proteins of the SGNH hydrolase superfamily—named after the conserved amino acids serine, glycine, asparagine, and histidine—play important roles due to their broad substrate specificity and enzymatic activity on carbohydrates (Anderson et al., 2022). Despite their biochemical significance, the role of fungal SGNH proteins, particularly in plant-pathogen interactions, remains poorly understood.

The use of computational approaches has been of great assistance in determining the roles of proteins. These methods have helped save time and money, as well as speed up research on the demanded interactions with small molecular weight substances. The molecular docking technique is considered to be among the most effective *in silico* methods for discovering novel bioactive compounds inside massive chemical libraries (Usta et al., 2023). The docking score of a small molecule is determined by the primary binding mode of that molecule's primary binding mode within a target binding pocket at the time of formation. With molecular docking, as opposed to *in vitro* approaches, the cost is lower and the process is completed more quickly (Sati et al., 2022; Demirel et al., 2024). Molecular docking, as a structure-based computational approach, has proven to be a powerful tool in predicting the interaction between proteins and small molecules (Fan et al., 2019). It has been widely employed in drug discovery and agrochemical development to screen and rank candidate inhibitors from large compound libraries. For instance, docking methods have facilitated the design of novel succinate dehydrogenase inhibitors (SDHIs) such as β-ketonitriles, pyrazole-4-acetohydrazide derivatives, and ring-opened pimprinine derivatives bearing (thio)amide groups, which have shown antifungal potential *in vitro* and *in silico* (Wang et al., 2021; Cheng et al., 2023; Zhou et al., 2023).

The aim of this study was to determine the antagonistic properties of isolates *C. rosea*, *T. harzianum*, and *B. mojavensis* against *B. cinerea*, to test the mutual interactions of these antagonist isolates under *in vitro* conditions, and the effects of these antagonists investigate on the germination of tomato seeds, the root and shoot length. This work also attempted to assess the possible antifungal activity of new compounds by utilizing a molecular docking approach to determine the interaction between metabolites from *C. rosea*, *T. harzianum*, and *B. mojavensis* and the target, a pathogenic protein from *B. cinerea*.

MATERIALS AND METHODS

In this study, the local genotype Süper tomato variety was used as the plant material, which is commonly cultivated in Iğdır province (Özden, 2019). The *B. cinerea* M2-1 (Genbank Accession Number: OM349592.1), *T. harzianum* C7-3 (Genbank Accession Number: PP919450), *C. rosea* C6-4 (Genbank Accession Number: PP784709), and *B. mojavensis* K193 (Genbank Accession Number: PP455489) isolates were obtained from the Culture Collection of the Department of Plant Protection, Faculty of Agriculture, Iğdır University.

In vitro tests of antagonists against *Botrytis cinerea*

Botrytis cinerea, *T. harzianum* C7-3, and *C. rosea* C6-4 isolates were cultured on Potato Dextrose Agar (PDA; Neogen, USA) for 7 days. A small dish of pathogen mycelia (5 mm diameter) was transplanted from the culture and placed on the centre of the PDA (9 cm). Similarly, two 5 mm diameter mycelial discs from *T. harzianum* C7-3 and *C. rosea* C6-4 were placed on either side of the pathogen (1 cm from edge petri plate). The *B. mojavensis* K193 stored at -80°C was initially revived by plating onto Tryptic Soy Agar (TSA Merck, Darmstadt, Germany-105458) and incubating at 24 ± 2°C for 48 hours. The bacterial colonies were then stored at +4°C for daily use. A pathogen disc (5 mm diameter) was placed at the center of petri plate, and bacterial culture was inoculated using line streaks 1 cm from both sides of petri plate. The experiment was conducted with four replications, and the petri plates containing only the pathogen (without fungal or bacterial antagonist inoculation) were considered as the control group. The petri plates were incubated at 24 ± 2°C (Hang et al., 2005), and the inhibition rate was measured on the 7th day. The inhibition rate (%) was calculated by measuring the fungal colony diameter in the control petri plates and the fungal colony diameter in the petri plates inoculated with the candidate antagonist, using the following formula (1) for percent inhibition (Muniroh et al., 2019).

Inhibition ratio (%) = [(Control fungal colony diameter – Treated fungal colony diameter) / Control fungal colony diameter] × 100.

Determination of the interactions between antagonists

Trichoderma harzianum and *C. rosea* isolates were cultured on PDA for 7 days, in order to determine the interactions between the fungal and bacterial candidate antagonists. The *B. mojavensis* K193 isolate was incubated on TSA for 48 hours at 24 ± 2°C. The combinations were designed as follows: *T. harzianum* × *C. rosea*,

T. harzianum × *B. mojavensis*, and *C. rosea* × *B. mojavensis* on PDA (9 cm). In the *T. harzianum* × *C. rosea* pairing, a 5 mm diameter discs from the fungal cultures were positioned 1 cm from the edge of the petri plate, facing each other. In the pairings of *T. harzianum* × *B. mojavensis* and *C. rosea* × *B. mojavensis*, a 5 mm diameter disc of the fungal candidate antagonist was positioned at the central part of the petri plate. *Bacillus mojavensis* K193 colonies inoculated on both sides of the disc, 1 cm from the edge of the petri plate. In addition, a 5 mm diameter mycelial discs of *T. harzianum* and *C. rosea* were placed at the center of PDA as the control group. The experiments were conducted with four replications, and fungal colony diameters were measured on the 7th day. Inhibition ratio was calculated according to formula 1.

Determination of the effects of antagonists on the germination of tomato seeds

The tomato seeds were subjected to surface disinfection in a 2% sodium hypochlorite (NaOCl) solution for 3 minutes. Afterward, the seeds were rinsed three times with sterile distilled water and placed on filter paper to dry at room temperature (Tunalı et al., 2018). To prepare the *T. harzianum* C7-3 and *C. rosea* C6-4 spore suspension were cultured on PDA for 7 day at 25°C. After, distilled water was added on petri plates and then scraped off with a sterile spatula. The wash solution was filtered through four layers of sterile gauze and concentration of the spore suspension was adjusted to 10^6 spores ml^{-1} using a hemocytometer. The seeds were maintained in the suspension (10^6) for 30 min and were then placed on petri plates containing Water Agar (WA; Oxoid, France), with 10 seeds per plate. The bacterization of seeds with *B. mojavensis* K193 isolate was performed prior to sowing. The bacterial isolate was inoculated into 250 ml flasks containing 50 ml of Nutrient Broth (NB, Merck 70122) and incubated at 24 ± 2°C for 48 hours while shaking at 150 rpm. The cultured bacteria were centrifuged at 3500 rpm for 15 minutes, and the resultant pellet was resuspended in 100 ml of 0.1% Carboxymethyl Cellulose (CMC). The bacterial suspension was prepared to a concentration of OD_{600nm} = 0.1. The tomato seeds were immersed in this suspension for 30 minutes before being placed on WA, with 10 seeds per plate (Akbaba and Özaktan, 2018). Tomato seeds were maintained for 30 minutes in sterile distilled water as a control (10 seeds per plate). The experiment was set up with three replications, and petri plates containing the tomato seeds were incubated at 25°C for 7 days. At the end of this period, root and shoot lengths of the seeds were measured, and the germination percentage was calculated according to the formula (2) from Christopher et al. (2010).

Germination Percentage = (Number of germinated seeds/Total number of seeds) ×100.

Preparation of ligand/target and molecular docking

The amino acid sequences of BcRAE (rhamnogalacturonan acetylesterase), BcFAT (fatty acyltransferase), and HOG1_BOTFB (Mitogen-activated protein kinase hog1) from *B. cinerea* were obtained from the NCBI database under accession numbers XM_001547332.2, XM_024693978.1, and A0A384K4V3. These proteins were selected due to their reported roles in fungal virulence and pathogenicity in *B. cinerea*, as demonstrated by Xu (2000), Moriwaki et al. (2006), Zhang et al., (2021), and Anderson et al. (2022). Multiple alignment of protein sequences identified conserved sections, and homology modeling of *B. cinerea* three pathogenic fungal proteins was carried out using Swiss-Model (Waterhouse et al., 2018). In order to do additional analysis, the 3D structures that were generated were uploaded to the PROCHECK platform within the Structural Analysis and Verification (SAVES 6.0) system (https://saves.mbi.ucla.edu/). The pdb. files obtained from the Swiss-model were used as receptors in docking studies.

The UCSF Chimera Software was utilized to enhance the target protein structure by eliminating undesired ligands, metals, and ions. This program enables the display, profiling, and analysis of chemical libraries derived from many origins, hence assisting in the enhancement of compound selection methodologies (Pettersen et al., 2004; Demirel, 2021; Sancaktaroğlu et al., 2023). These three-dimensional representations of BCAs metabolites were obtained through the PubChem database, which can be accessed at https://pubchem.ncbi.nlm.nih.gov/ (Table 4). Docking experiments employed these structures as ligands. UCSF Chimera software (version 1.16) of University of California, San Francisco, minimized ligand energy. "Gasteiger's methods were employed to optimize the ligand(s) with a zero net charge using the UCSF Chimera software. Thus, optimized ligands were saved in "mol2 format" for molecular docking. Using the UCSF Chimera, the chosen BCA compounds (*T. harzianum, C. rosae,* and *B. movajensis*) were docked against specific target proteins of the *B. cinerea*. In order to determine the ligand ranking according to the empirical binding free energy (kcal mol^{-1}), this tool employs a gradient optimization strategy throughout its local optimization phase. An exhaustive examination and comparison of the docked sites of the target proteins and ligands was conducted using UCSF Chimera following the conclusion of the docking technique. Then, the docking results were visualized using BIOVIA Discovery Studio Visualizer v24.1.0.23298, which allowed for the representation of 2D interactions.

Statistical analysis

The data obtained from the study were analyzed using the Statistical Package for Social Sciences Program (SPSS 2008, Version 17; SPSS Inc., Chicago). These data were subjected to one-way ANOVA for variance analysis, and the differences between the treatments were determined using Duncan's Multiple Comparison Test ($p<0.05$).

RESULTS and DISCUSSION

Results

The results of dual-culture tests conducted to identify candidate antagonists fungal and bacterial against *B. cinerea* were effective in inhibiting the mycelial growth of the pathogen to varying degrees. According to the results of the ANOVA test, the antagonistic relationship between the pathogen and the BCAs was found to be statistically significant ($p< 0.05$). The findings of the study demonstrating the biocontrol potential of these isolates. Among the isolates, *T. harzianum* C7-3 was found to have the highest biocontrol effect against *B. cinerea* M2-1, with a 56% inhibition rate compared to the control (Table 1).

Table 1. Effects of candidate antagonist applications on mycelial growth of *Botrytis cinerea*.

	Botrytis cinerea M2-1	
Aplications	Mean (cm) ± stn deviation*	Inhibition rate (%)
Clonostachys rosea C6-4	6.2 ± 0.44b	26.2
Trichoderma harzianum C7-3	3.7 ± 0.63c	56.0
Bacillus mojavensis K193	5.7 ± 0.41b	32.1
Control	8.4 ± 0.12a	-

*: According to the Duncan's multiple range test, the differences between means indicated by different letters in the same column are significant at p<0.05.

In the study, the morphological changes on hyphae and decrease on spore production of *B. cinerea* M2-1 and caused by isolates of *C. rosea* C6-4, *T. harzianum* C7-3 and *B. mojavensis* K193 were notable (Figure 1).

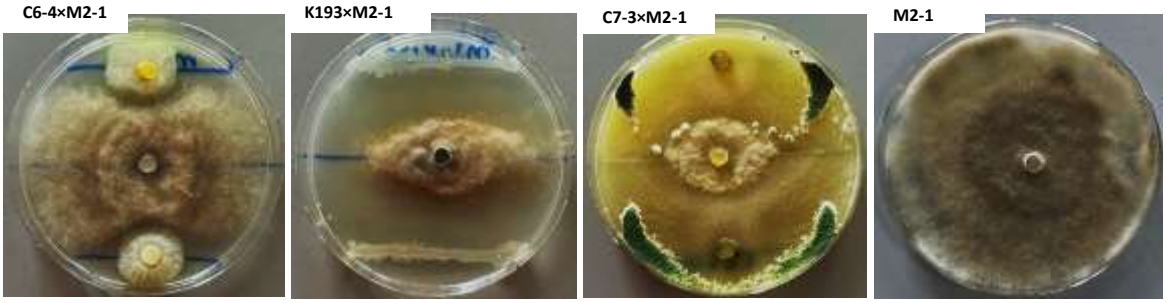

Figure 1. *In vitro* biocontrol effects of *Clonostachys rosea* C6-4, *Bacillus mojavensis* K193 and *Trichoderma harzianum* C7-3 against *Botrytis cinerea* M2-1.

In the pairings conducted to determine the interactions of candidate antagonist isolates, *T. harzianum* was found to have a 31.2% inhibition rate on *C. rosea*. Furthermore, in the *T. harzianum* × *B. mojavensis* pairing, the fungal antagonist's mycelial growth was inhibited by the bacterial isolate (Table 2). In the *C. rosea* × *B. mojavensis* pairing, the slow growth of *C. rosea* resulted in its failure to encounter the bacterial isolate by the end of the specified period (Figure 2). Subsequent observations (on day 22) showed that this fungus continued its normal development, but its mycelial growth did not pass over the bacterial isolate.

Table 2. The interactions and percentage of inhibition results of candidate antagonist isolates under *in vitro* conditions.

Combinations*	Mean (cm) ± stn deviation	Inhibition rate (%)
C6-4×C7-3	2.1 ± 0.05 c	34.4
C6-4×K193	2.6 ± 0.12 b	18.8
C6-4 (Control)	3.2 ± 0.25 a	-
C7-3×C6-4	8.5 ± 0.00 a	0.00
C7-3×K193	6.8 ± 0.05 b	20.0
C7-3 (Control)	8.5 ± 0.00 a	-
*: C6-4; *Clonostachys rosea*, C7-3; *Trichoderma harzianum*, K193; *Bacillus mojavensis*		

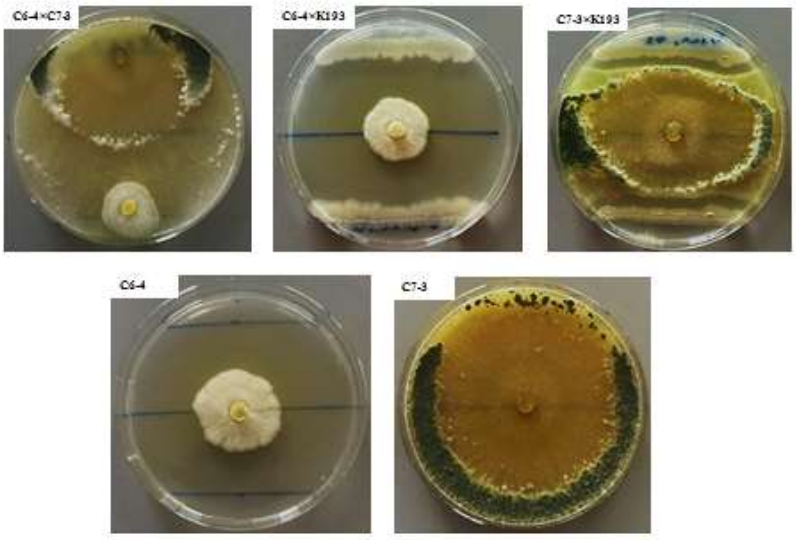

Figure 2. The interactions of *Clonostachys rosea* C6-4, *Trichoderma harzianum* C7-3, and *Bacillus mojavensis* K193 candidate antagonists under *in vitro* conditions.

The results obtained in this study, where the effects of candidate antagonists on tomato seedling length, root length, and germination percentage were determined, are presented in Table 3. The highest shoot (4.02 cm) and root (3.57 cm) lengths were recorded for the *B. mojavensis* isolate. Among the tested isolates, the highest germination percentage was recorded at 86.7% for the *T. harzianum* isolate.

Table 3. Effects of candidate antagonist isolates on shoot length, root length, and germination percentage of tomato seeds.

Species	Root length (cm) (Mean±Std deviation)*	Shoot length (cm) (Mean±Std deviation)	Germination percentage (%)
Clonostachys rosea C6-4	3.09 ± 3.08 ab	3.11 ± 2.58a	76.7
Trichoderma harzianum C7-3	2.11 ± 1.16 b	1.76 ± 1.03b	86.7
Bacillus mojavensis K193	3.57 ± 2.51 a	4.02 ± 2.99a	76.7
Control	2.62 ± 1.94 ab	3.33 ± 2.45a	76.7

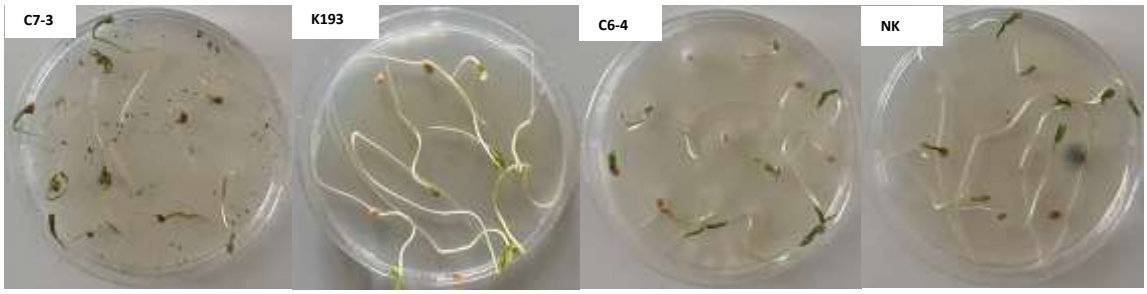

Figure 3. Effects of *Trichoderma harzianum* C7-3, *Bacillus mojavensis* K193 and *Clonostachys rosea* C6-4 on tomato seed germination (NK: Negative control).

Utilizing a homology modeling technique, we constructed a three-dimensional model of the BcRAE, BcFAT, and HOG1_BOTFB proteins that significantly contributing to the pathogenicity of *B. cinerea*. For the purpose of studying interactions with biological agent ligands, the pdb. files of proteins that were produced by homology modeling were utilized as receptors. Through docking with the *B. cinerea* receptor, twelve ligands were enhanced. Among the total 12 BCA metabolites, *T. harzianum* metabolites showed the best docking score with better or almost equal binding energy with 3 pathogenic proteins of *B. cinerea* (Table 4). The current investigation revealed that out of the four compounds examined from *T. harzianum*, 1,8-Dihydroxy-3-methylanthraquinone (10208) exhibited the highest inhibition of BcRAE (-6.7 kcal mol^{-1}), BcFAT (-6.9 kcal mol^{-1}), and HOG1_BOTFB (-9.0 kcal mol^{-1}), respectively compared to the other compounds subjected to docking energy testing. Within the four metabolites examined, verticillin D from *C. rosea* had the greatest docking energy with the BcRAE, BcFAT, and HOG1_BOTFB, with corresponding vina scores of -5.1 kcal mol-1, -5.0 kcal mol^{-1}, and -7.6 kcal mol^{-1}. Picolinic acid (1018) showed the highest docking score among the 4 ligands of *B. movajensis* for BcRAE (-5.3 kcal mol^{-1}), BcFAT (-5.2 kcal mol^{-1}) and HOG1_BOTFB (6-.3 kcal mol^{-1}). In addition, the interactions of the metabolites of all three biological agents with the BcRAE, BcFAT and HOG1_BOTFB proteins of *B. cinerea* were examined, along with those with the highest docking scores and were illustrated by Chimera (Figure 4-6).

In the *in vitro* assays, *T. harzianum* C7-3 isolate exhibited the highest inhibition rate (56%) against the mycelial growth of *B. cinerea* M2-1 isolate (Table 1). This finding was also supported by *in* silico docking results. Among the tested metabolites as *in* silico, 1,8-Dihydroxy-3-methylanthraquinone (PubChem ID: 10208), derived from *T. harzianum*, showed the strongest binding affinities with the pathogenicity-related proteins of *B. cinerea*, including BcRAE (-6.7 kcal mol^{-1}), BcFAT (-6.9 kcal mol^{-1}), and HOG1_BOTFB (-9.0 kcal mol^{-1}) (Table 4). These consistent results between *in vitro* inhibition and docking scores may indicate that *T. harzianum* has a high antifungal potential, possibly exerting its effects by targeting the virulence-related proteins of *B. cinerea*.

Table 4. Interaction analysis scores of pathogenicity associated proteins of *Botrytis cinerea* and biocontrol agent compounds.

Biological agents and their ligands		AutoDock Vina Scores of *Botrytis cinerea* fungal proteins and biological agent ligands (kcal mol^{-1})		
Biological agent name	Ligand PubChem ID	BcRAE	BcFAT	HOG1_BOTFB
Clonostachys rosea	146682313	-5.2	-4.9	-5.1
	44566357	-5.1	-5.0	-7.6
	70697848	-5.0	-5.1	-6.0
	449123	-5.4	-5.2	0
Trichoderma harzianum	54697782	-5.8	-4.9	-6.5
	10208	-6.7	-6.9	-9.0
	76326344	-6.1	-6.2	-7.1
	15719532	-5.5	-5.8	-6.0
Bacillus mojavensis	1018	-5.3	-5.2	-6.3
	1017	-4.5	-4.4	-5.2
	14529	-4.8	-5.5	-5.7
	179	-3.9	-3.7	-3.3

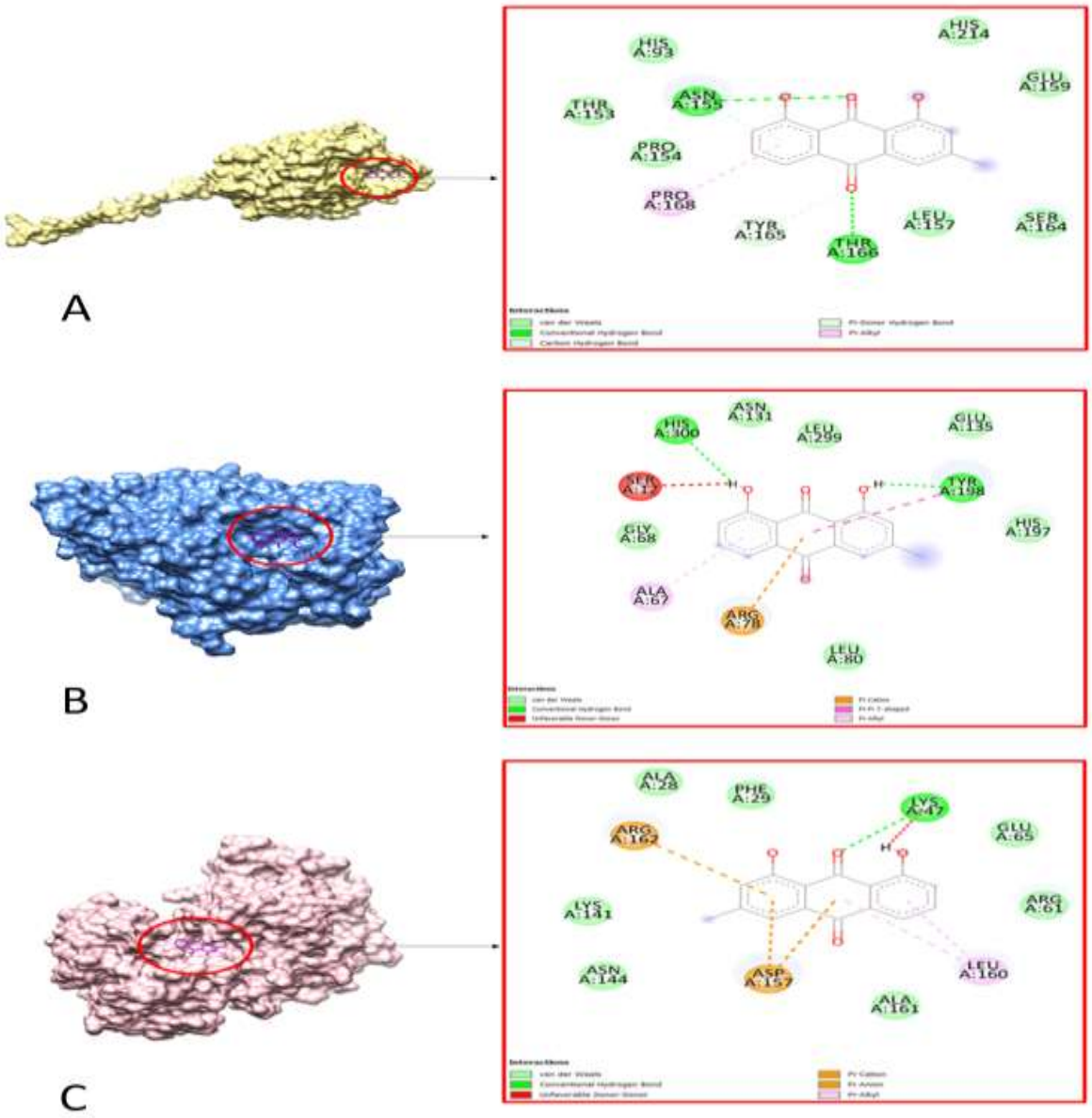

Figure 4. 3D structural bindig pose and 2D representations of interactions established of 1,8-Dihydroxy-3-methylanthraquinone (10208) from *Trichoderma harzianum* in relation to the BcRAE (A), BcFAT (B) and HOG1_BOTFB (C) pathogenic proteins of *Botrytis cinerea*.

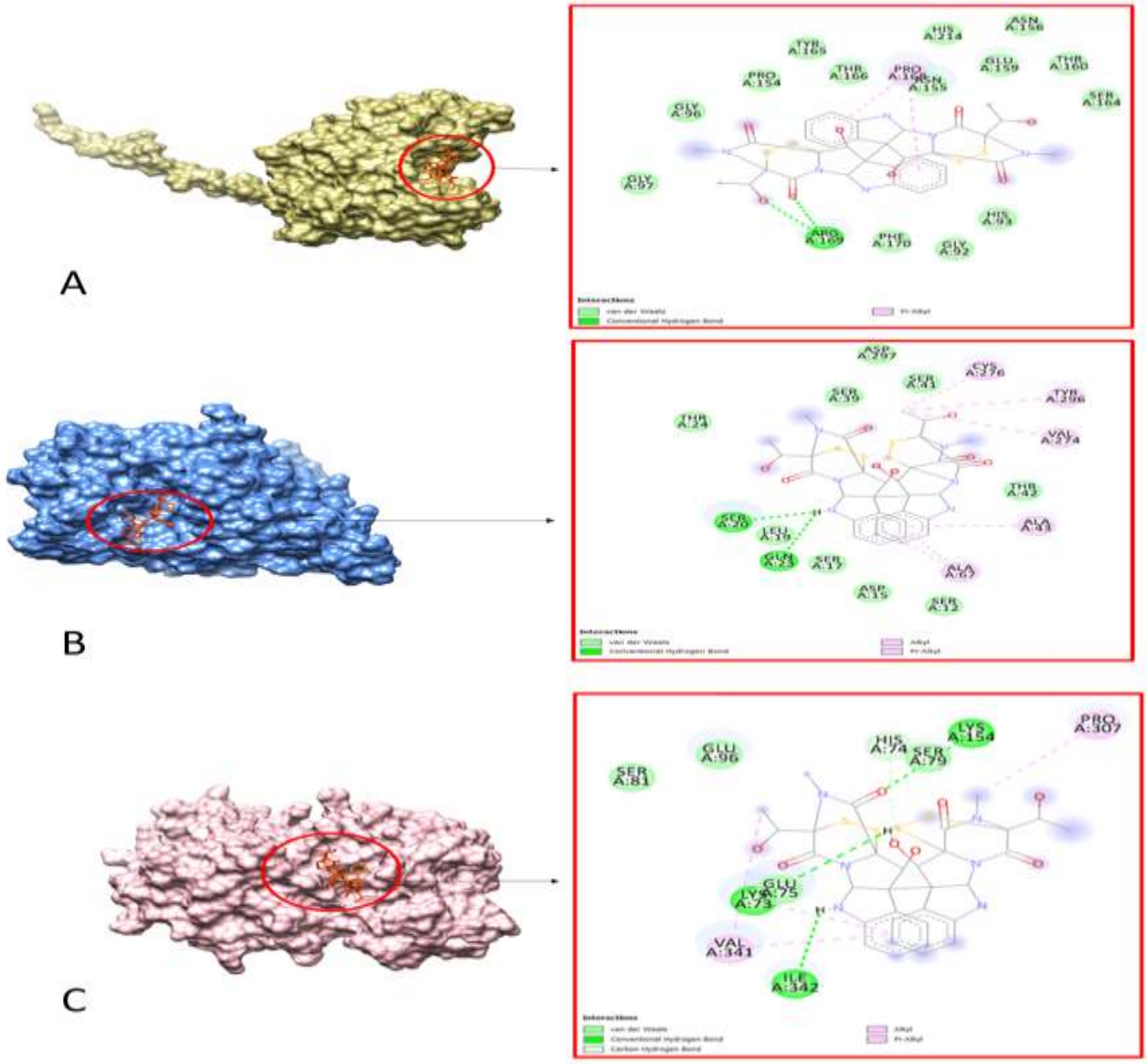

Figure 5. 3D structural bindig pose and 2D representations of interactions established of verticillin D (44566357) from *Clonostachys rosea* in relation to the BcRAE (A), BcFAT(B) and HOG1_BOTFB (C) pathogenic proteins of *Botrytis cinerea*.

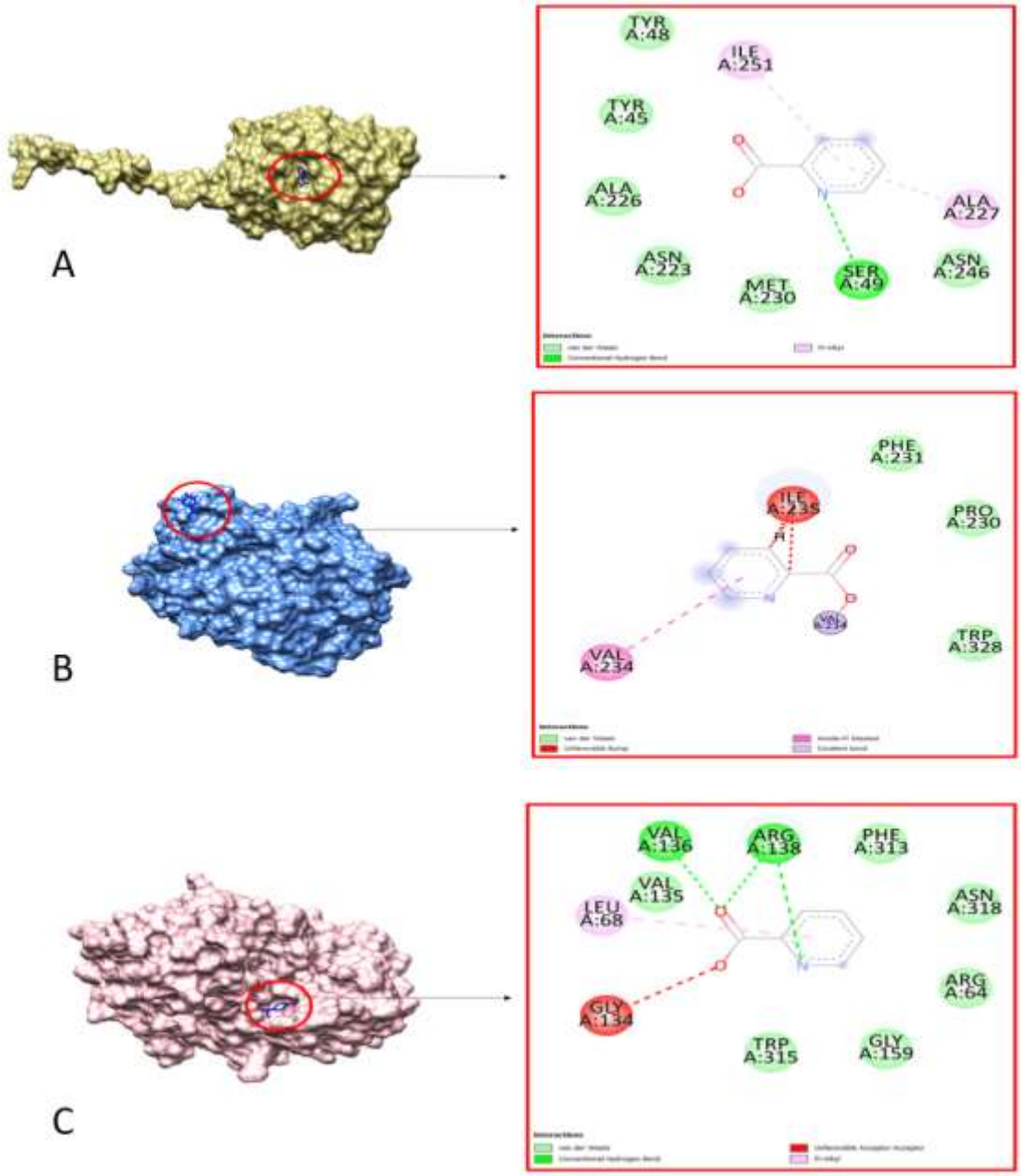

Figure 6. 3D structural bindig pose and 2D representations of interactions established of picolinic acid (1018) from *Bacillus mojavensis* in relation to the BcRAE (A), BcFAT(B) and HOG1_BOTFB (C) pathogenic proteins of *Botrytis cinerea*.

Discussion

Botrytis cinerea causes significant crop losses in economically valuable plants such as tomato. Considering the harmful environmental effects of commonly used fungicides and the acquired resistance against the pathogen, biocontrol method present a significant alternative in the management of this pathogen. The genus *Clonostachys*, *Trichoderma*, and *Bacillus* are among the most effective biological control agents for phytopathogens (Kumar et al., 2017; Fira et al., 2018; Sun et al., 2020; Senkovs et al., 2021; Pandit et al., 2022).

In this study, the effects of *C. rosea*, *T. harzianum*, and *B. mojavensis* isolates on the control of *B. cinerea* were investigated. The results showed that the tested fungal and bacterial isolates effectively controlled the mycelial growth and sporulation of *B. cinerea* (Figure 2), which is consistent with the literature (Cota et al., 2008; Saraiva et al., 2015; You et al., 2016; Saddek et al., 2020; Nawrocka et al., 2022; Meng et al., 2022).

This biocontrol agent parasitizes *B. cinerea* by directly infecting its mycelium and spores, competing for the same nutritional resources, and producing enzymes such as proteases and chitinases that inhibit the fungus

growth (Meng et al., 2022). *Clonostachys rosea* is associated with the activation of many processes, encompassing the release of cell wall-destroying enzymes, secondary metabolites exhibiting antifungal properties, and the enhancement of plant systems related to defense (Sun et al., 2020). Similarly, *Trichoderma* has been shown to be effective in inhibiting fungal plant pathogens by producing β-1,3-glucanase, chitinase, cellulase, proteases, and both volatile and non-volatile antibiotics (Muniroh et al., 2019). Moreover, both *C. rosea* and *Trichoderma* spp. can suppress *B. cinerea* sporulation through mycoparasitism (You et al., 2016). *Bacillus* spp. have garnered significant interest as biological control agents due to their ability to synthesize a wide range of broad-spectrum antibiotics, toxins, enzymes, and endospores. Biocontrol products containing several strains that have been developed for commercial use and with extended shelf lives are now available (Kiesewalter et al., 2020; Blake et al., 2021). *Bacillus thuringiensis*, *B. velezensis*, *B. amyloliquefaciens*, *B. subtilis*, and *B. mojavensis* are the most widely used for the biological control of phytopathogens (Mizumoto et al., 2007; Martínez-Absalón et al., 2014; Poveda et al., 2020). Recent studies have shown that *B. mojavensis* is a close relative of *B. subtilis* (Calvo et al., 2010; Earl et al., 2012). Certain of *B. mojavensis* strains are capable of endophytic colonization of plant tissues in intercellular spaces, without causing noticeable damage to the host plant. The colonization by *B. mojavensis* strains promotes plant growth, induces immune responses, suppresses plant pathogens through niche competition, and consequently enhances crop yield (Diabankana et al., 2021).

This study examined the effects of candidate antagonists on germination, root and shoot lengths of tomato seeds. Indeed, in addition to the antifungal effects of each biocontrol agent used in the study, it is known that they have numerous positive effects on plant growth. These beneficial effects are associated with the enhancement of plant growth parameters, increased uptake of macro and micronutrients, enhanced photosynthetic activity, activation of plant secondary metabolism, and accumulation of polyphenols (Carillo et al., 2020; Vukelić et al., 2021; Guzmán-Guzmán et al., 2023). *Trichoderma harzianum* has been shown to promote plant growth in tomato by increasing leaf pigment content and photosynthetic activity (Fiorini et al., 2016). Furthermore, *T. harzianum* (T-21 and T-68) and *Trichoderma koningiopsis* (T-35 and T-51) have been reported to promote growth and induce resistance in tomato seedlings through the production of gibberellins and indole-3-acetic acid (You et al., 2016). Additionally, *C. rosea* enhances plant resistance to *B. cinerea* by activating defense mechanisms (Meng et al., 2022). Treatment of tomato leaves with *C. rosea* resulted in significant increases in the activity of enzymes such as phenylalanine ammonia-lyase, polyphenol oxidase, and glutathione S-transferase, as well as elevated levels of phytohormones, including gibberellic acid and salicylic acid (Mouekouba et al., 2014).

Significant successful results have been recorded applying bacterial × fungus, fungus × fungus, and bacterial × bacterial mixtures in the control of plant pathogens (Kumar et al., 2015; Li et al., 2023). To prepare better, more compatible, synergistic, and suitable mixtures of BCAs, further understanding of the interactions between these antagonists is required (Krauss, 2013). In this study, the interactions between *T. harzianum* × *C. rosea*, *T. harzianum* × *B. mojavensis*, and *C. rosea* × *B. mojavensis* isolates were tested under *in vitro* conditions. The results showed that the *B. mojavensis* had negative effect on *T. harzianum*. In the *T. harzianum* × *C. rosea* pairing, the rapid growth of the *Trichoderma* provided a competitive advantage for space, thereby reducing *C. rosea* mycelial growth in comparison to the control. Similarly, ten Hoopen et al. (2010) demonstrated that the combination of *C. rosea* and *T. harzianum* could be used in mixture against *B. cinerea*, but competition between the two species occured. They suggested that adjusting the ratio of the mixture could overcome this issue when used in combination. Furthermore, Krauss (2013) reported that increasing the concentration of *C. rosea* significantly reduced the growth of *T. harzianum* (in *C. rosea* × *T. harzianum* mixture). Additionally, *T. harzianum*'s higher growth rate resulted in more physical contact between hyphae and greater exposure to mycoparasitism, making *T. harzianum* more susceptible to hyphal damage. However, there are several factors that influence the success of mixture applications in the control of plant diseases. A variety of biotic and abiotic environmental factors, including water, pH, temperature, and the existence of pesticides, ions of metal, and other soil antagonists, should be considered while organizing the application of antagonistic isolates (Kredics et al., 2003).

In this study, two *B. cinerea* proteins, BcRAE and BcFAT, classified within the SGNH hydrolase/CDIP families, were selected for docking analysis based on their potential involvement in fungal virulence and host cell manipulation. These proteins have been reported to function as secreted effectors, likely contributing to necrotrophic infection strategies. Additionally, the mitogen-activated protein kinase (MAPK) pathway has been implicated in eukaryotic stress response and pathogenicity regulation. HOG1, a member of the MAPK family, regulates adaptive responses to osmotic stress in *Saccharomyces cerevisiae* and its homologs in fungal phytopathogens (e.g., *B. cinerea*) have been associated with virulence (Schaeffer and Weber, 1999; Xu, 2000; Moriwaki et al., 2006). In this study, the *B. cinerea* HOG1 homolog (NCBI Accession No: A0A384K4V3) was included in docking experiments to assess its potential interactions with antagonist-derived secondary metabolites.

Our objective was to theoretically clarify the binding manner between metabolites of BCAs and three proteins (BcRAE and BcFAT belong to CDIPs and HOG1_BOTFB member of MAPK) related with the pathogenicity/virulence of *B. cinerea* by molecular docking. When the docking scores of the interaction between pathogenic proteins and ligands are taken into account, it is evident that the antifungal possibilities of the ligands from *T. harzianum* and *C. rosea* are significantly high. Nevertheless, the docking scores of fungal proteins with ligands from another biological agent (*B. mojavensis*) indicate that their binding energies are rather similar. Owing to the outcomes of the present study, the antagonistic interaction that exists between BCAs and *B. cinerea*, as well as the docking results of BCA metabolites with pathogenic fungal proteins, are supportive of one another. The gray mold disease in tomatoes induced by *B. cinerea* can be reduced by harzianolide, anthraquinone C, and harzianopyridone (Vinale et al., 2008; Vargas et al., 2009; Cui et al., 2015; Plaza et al., 2015; Saravanakumar et al., 2016). In the *in vitro* antagonistic assay, *T. harzianum* C7-3 demonstrated a higher inhibition rate (56%) against *B. cinerea* M2-1 compared to the other tested antagonists. Although no direct mechanistic analysis was performed, this biological activity was further explored through *in silico* docking to examine potential interactions between metabolites and key pathogenicity-related proteins of *B. cinerea*. This was done in order to investigate the potential mechanism that is connected with the antifungal activity of metabolites of BCA against *B. cinerea*. According to Table 4, the four selected metabolites from *T. harzianum* exhibited relatively high binding affinities (i.e., more negative docking scores) with key pathogenicity- and virulence-related proteins of *B. cinerea*. Although no statistical correlation analysis was performed between the docking scores and the observed biological activity, these *in* silico findings may offer preliminary insights into possible antifungal mechanisms at the molecular level. It is plausible that these metabolites may act individually or even cooperatively to interfere with the function of target fungal proteins. However, this hypothesis requires further experimental validation through comprehensive *in vivo* and biochemical studies. In a previous study, Saravanakumar et al. (2018) demonstrated that *T. harzianum* CCTCC-SBW0162 significantly reduced gray mold disease severity by 80.7% in greenhouse conditions and exhibited a 90.6% inhibition rate *in vitro*. To elucidate the molecular basis of this antagonistic effect, the authors also performed docking analyses between fungal metabolites and *B. cinerea* virulence-related proteins. Our docking results, particularly regarding *T. harzianum*-derived metabolites, are in agreement with those findings, suggesting that similar inhibitory mechanisms may be involved. Nonetheless, the theoretical nature of docking must be emphasized, and its predictive value should be interpreted with caution in the absence of functional validation.

A noteworthy aspect of this study is the consistency observed between the biological activity of *T. harzianum* and the theoretical predictions derived from molecular docking analyses. The superior antagonistic effect exhibited by *T. harzianum in vitro* appears to align with the strong binding affinities of its secondary metabolites toward key virulence-related proteins of *B. cinerea*. This alignment suggests that the biocontrol efficacy of *T. harzianum* may not be limited to general antagonistic mechanisms such as competition and mycoparasitism, but could also involve the targeted inhibition of specific molecular pathways essential for fungal pathogenicity. Such complementary findings from different methodological approaches enhance the credibility of the observed antifungal activity and highlight the potential of integrating computational analyses into the early screening of biocontrol candidates.

CONCLUSION

Botrytis cinerea is a widespread and economically important pathogen, and its management through biological control strategies is gaining increasing attention due to the limitations and environmental concerns associated with chemical fungicides. In this study, the antagonistic isolates *T. harzianum*, *C. rosea*, and *B. mojavensis* demonstrated varying degrees of inhibitory effects against *B. cinerea* under *in vitro* conditions. Among them, *T. harzianum* showed the highest inhibition and may represent a promising candidate for biocontrol applications.

Furthermore, molecular docking results provided theoretical insights into the possible interactions between secondary metabolites of these isolates and the virulence-associated proteins of *B. cinerea*. Notably, some metabolites derived from *T. harzianum* exhibited strong binding affinities with key pathogenicity-related proteins, which may indicate potential antifungal mechanisms at the molecular level.

However, it is important to emphasize that molecular docking is a predictive tool, and the theoretical interactions observed *in silico* require further validation through detailed *in vivo* and biochemical studies. Therefore, the findings of this study may serve as a foundation for future research aiming to develop integrated and sustainable approaches for the control of gray mold disease in tomatoes.

Declaration of Interests
The authors have declared no conflict of interest.

Author's Contributions
The contribution of the authors is equal.

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Original Article

Marketing Strategies of Food and Beverage Companies in the ISO 500 List: A Study on Their Websites

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ABSTRACT

The widespread use of the internet has led to profound changes in business marketing strategies and has strengthened the importance of digital marketing. Websites have evolved beyond being mere informational platforms and have become critical tools for building brand identity, enabling customer engagement, and managing sales processes. Effective and strategic use of websites plays a significant role in achieving key marketing goals such as brand awareness, customer loyalty, and sales growth. Therefore, websites are indispensable tools for the successful implementation of modern marketing strategies. This study aims to analyze the websites of the largest food and beverage companies in Turkey from a marketing strategy perspective, presenting a comprehensive profile of the marketing strategies used on these websites and identifying the strengths, weaknesses, and areas with potential for improvement. The research findings indicate that while companies generally apply an effective strategy in terms of product mix on their websites, the information regarding distribution and pricing strategies is rather limited. In terms of promotional activities, some areas provide detailed information, whereas others fall significantly short. In the study, the effectiveness of companies in utilizing their websites from a marketing strategy perspective was evaluated based on their inclusion of specific marketing criteria, and classified according to a 19-point scoring system. As a result, it was found that 32.4% of the companies demonstrated a moderate level of effectiveness, 52.9% a high level, and 14.7% a very high level. Accordingly, it is evident that the analyzed companies use their websites at a level above average in terms of marketing strategies. However, significant areas for improvement were also identified in their digital marketing efforts. Notably, there is a considerable development potential in areas such as online sales, newsletter subscriptions, annual reports, and frequently asked questions.

Key words: Food, beverage, company, marketing, website

ISO 500 Listesindeki Gıda ve İçecek İşletmelerinin Pazarlama Stratejileri: Web Siteleri Üzerine Bir Araştırma

ÖZ

İnternetin yaygınlaşması, işletmelerin pazarlama stratejilerinde köklü değişimlere yol açmış ve dijital pazarlamanın önemini güçlendirmiştir. Web siteleri, yalnızca bilgilendirme platformu olmanın ötesine geçerek marka kimliği oluşturma, müşteri etkileşimi sağlama ve satış süreçlerini yönetme açısından kritik bir araç haline gelmiştir. Etkili ve stratejik web sitesi kullanımı, marka bilinirliği, müşteri sadakati ve satış artışı gibi temel pazarlama hedeflerine ulaşmada önemli bir rol oynamaktadır. Bu nedenle, web siteleri, modern pazarlama stratejilerinin başarılı bir şekilde uygulanabilmesi için vazgeçilmez bir araçtır. Bu çalışma, Türkiye'de yer alan en büyük gıda ve içecek işletmelerinin web sitelerini pazarlama stratejileri açısından araştırarak, işletmelerin web sitelerinde kullandıkları pazarlama stratejilerinin kapsamlı bir profilini ortaya koymayı, başarılı olan, yetersiz olan ve gelişime açık olan alanları belirlemeyi amaçlamaktadır. Araştırma bulguları, işletmelerin web sitelerinde ürün karması açısından etkili bir strateji uyguladığını, ancak dağıtım ve fiyat karmasına dair kriterler açısından web

sitelerinin genel anlamda daha sınırlı bilgi içerdiğini göstermiştir. Promosyon açısından ise bazı alanlarda daha kapsamlı bilgi sunulurken, diğer bazı alanlarda sunulan bilgilerin oldukça yetersiz kaldığı görülmektedir. Çalışmada işletmelerin pazarlama stratejileri açısından web sitesini etkin kullanım durumları, belirlenmiş olan pazarlama kriterlerine yer verme durumu baz alınarak, 19 kriter üzerinden yapılan puanlamayla sınıflandırılmıştır. Sonuç olarak, işletmelerin %32.4'ünün orta düzey, %52.9'unun yüksek düzey ve %14.7'sinin çok yüksek düzey etkinlik gösterdiği belirlenmiştir. Bu doğrultuda, incelenen işletmelerin web sitelerini pazarlama stratejileri açısından belirli bir etkinlik düzeyinin üstünde kullanabildikleri görülmüştür. Ancak yine de gıda işletmelerinin web sitelerindeki pazarlama stratejilerine ilişkin önemli gelişim alanları tespit edilmiştir. Online satış, bülten aboneliği, faaliyet raporları ve sıkça sorulan sorular alanlarına ilişkin verilerin ve stratejilerin yetersiz olduğu ve bu alanda önemli bir gelişim potansiyeli bulunduğu belirlenmiştir.

Anahtar kelimeler: Gıda, içecek, işletme, pazarlama, web sitesi

INTRODUCTION

With the widespread use of the internet, digital marketing has gained significant importance alongside traditional marketing channels and has become a critical marketing tool for companies. Having an internet marketing strategy enables companies to target the market more effectively by making their products easily accessible to those searching for them, thereby facilitating the delivery of the right product to the right consumer (Obednikovska et al., 2019). While traditional marketing is characterized by one-way communication from producer to consumer, technological advancements and the opportunities provided by the internet have enabled a two-way and continuously evolving communication process (Bulunmaz, 2016). Digital marketing has gained even more importance, especially during the COVID-19 pandemic, and companies have increasingly prioritized digital marketing efforts (Erdoğan, 2020; Alankuş, 2021; Rustamov, 2022).

Websites are among the most important components of digital marketing for companies (Çubukcu, 2010; Duygun and Alnıpak, 2017; Gedik, 2020; Widagdo and Roz, 2021; Sharma, 2023). Numerous studies in the literature indicate that well-designed, high-quality, and professional websites play a significant role in enabling companies to effectively communicate their activities to consumers and enhance their marketing success (Lee and Kozar, 2006; Mithas et al., 2006; Hernandez et al., 2009; Rahimnia and Hassanzadeh, 2013; Thongmak, 2022). Websites offer a valuable platform for companies to reflect their brand image, establish effective communication with their target audiences, and present the features of the products and services they offer. Furthermore, compared to traditional marketing tools, websites have several advantages from a marketing perspective (Kurtoğlu, 2016). Traditional marketing communication is often more costly compared to online communication. Additionally, printed materials such as brochures and posters, which hold an important place in traditional marketing, lose their effectiveness after being distributed or displayed, whereas websites can be continuously updated, enriched with new content, and thus create a long-term impact (Usta, 2007). Through this channel, companies can promote their products to large audiences at lower costs, provide after-sales services, and offer platforms where consumers can express their opinions and easily reach the company (Alan et al., 2018).

Along with these developments, studies in the field of digital marketing have increased, and research analyzing the websites of companies from a marketing perspective across various sectors has become more prominent in the literature. A review of the literature reveals several studies examining the marketing strategies of websites of companies operating in various sectors across Turkey. When evaluated on a sectoral basis, studies related to this topic have been conducted in the hospitality sector (Karamustafa et al., 2002; Bayram and Yaylı, 2009; Pamukçu and Arpacı 2016; Ceylan, 2018, Gönül and Erciş, 2023; Uçar, 2023; Eren et al. 2023), the textile sector (Özdemir-Öztürk 2022), the freight transportation sector (Duygun and Alnıpak 2017) and even in the fields of political marketing and political communication (Evren, 2015). Regarding the food sector, although there are various studies examining the websites of restaurants (Uygur et al., 2018), companies in the dairy sector (Basar and Deniz, 2019), and family-owned food and beverage businesses (Atik, 2016) from a marketing perspective, these studies generally focus on businesses in specific regions or particular sub-sectors. However, no study has been found that examines the websites of the largest food companies in Turkey from a marketing strategy perspective, considering the food sector as a whole across the country. Therefore, there is a significant gap in the literature in this area. In this context, researching the websites of the largest food companies in Turkey in terms of marketing strategies is crucial for identifying current practices and trends, as well as analyzing sectoral competition more closely. Organizing the websites of food companies in a way that meets consumer expectations and provides the information consumers need is also critical for consumer trust and brand loyalty. In this regard, this study aims to investigate the websites of the largest food companies in Turkey from a marketing strategy perspective, providing a comprehensive profile of the marketing strategies used on these websites, and identifying areas that are insufficient, successful, or open to development.

MATERIALS AND METHODS

The material for this study consists of the websites of food and beverage companies listed in the "ISO 500 Türkiye's Top 500 Industrial Enterprises" list, prepared by the Istanbul Chamber of Industry. The companies and, consequently, the websites to be analyzed were determined based on this list. From all the companies in this list, those falling under the "10 - Manufacture of Food Products" and "11 - Manufacture of Beverages" categories according to the NACE classification were selected, forming the sample for the study (Istanbul Chamber of Industry, 2024). In this context, a total of 106 companies are listed under the categories "10 - Manufacture of Food Products" and "11 - Manufacture of Beverages." However, due to three companies requesting not to have their names disclosed despite being listed, they appeared anonymously in the list, and two different companies operating under the same parent company using the same website, a total of 102 distinct websites were analyzed in the study. The analysis of the websites was conducted during the period of November and December 2024.

Table 1. Marketing Mix (4Ps) Analysis Criteria for Food Companies' Websites

4P Category	Criteria Sought on the Website	Description of the Criteria
Product	Product Categories	Does the website specify the categories or types of products that the company manufactures or sells?
	Product Features	Does the website provide information about the product content, nutritional values, or areas of use?
	Product Images	Are there photos of the products or images of their packaging?
	Certificates and Certifications	Are quality certificates, compliance standards, or other certifications related to the products shared?
Price	Discounts and Campaigns	Is information about discounts or promotional campaigns for the products provided?
	Payment Options	Are payment options such as cash, installments, credit card, bank transfer/EFT, or cash on delivery available? (Applicable only for companies with online sales)
	Product Prices	Are product price details provided on the website or on the platform where sales are conducted?
Place	Dealers / Distributors / Sales Points / Business Partners	Is information provided about dealers, distributors, sales points, or business partners where consumers can access the products?
	Online Sales / Platform Redirection	Does the website offer direct online sales, or, if not, does it redirect users to another sales platform owned by the company?
Promotion	Announcements/News	Does the company share various announcements or news to inform customers, business partners, and the public?
	Annual Reports	Are the company's annual activity reports shared on the website?
	Contact Information	Does the website provide communication channels such as a customer service number, email address, contact form, or live support for consumers to reach out to the company?
	Frequently Asked Questions (FAQ)/What You May Wonder	Is there a section where frequently asked questions about products or the company are answered?
	History/About	Is there a section providing information about the company, including its history and areas of activity?
	Language Options	Is there an option to select a language other than Turkish on the website?
	Newsletter Subscription	Does the company provide an option for users to subscribe to an e-newsletter?
	Social Media Redirects	Does the website provide links to the company's social media accounts? (e.g., Twitter, Instagram, Facebook)
	Social Responsibility / Sustainability Projects	Does the company share information or reports about its social responsibility or sustainability projects?
	Vision, Mission, Values	Does the company clearly express its vision, mission, and values?

In this study, the content analysis method was used to analyze the marketing strategies on the websites of Turkey's largest food companies. Content analysis is a research method that systematically examines various

types of data, such as visual and verbal content, and is widely used across many disciplines. This method enables a deeper analysis and interpretation of events or phenomena by classifying them under specific categories (Harwood and Garry, 2003). The content analysis method is also one of the most commonly used approaches for examining and researching websites for various purposes (Perry and Bodkin, 2000; Weber et al., 2006; Hurwitz et al., 2017; Sparacino et al., 2024).

In the study, the analysis of the companies' website marketing strategies was based on the marketing mix (4Ps: Product, Price, Place, Promotion), and the websites were subjected to content analysis according to various predefined criteria. In determining these criteria, several factors were taken into account: the marketing strategies that a food company might consider when designing its website, marketing trends in the food sector, consumer expectations, sectoral competition dynamics, and previous studies that examined websites of companies in different industries using the content analysis method. In this context, while the number of criteria under each component of the marketing mix was generally balanced, more sub-criteria were included under the "Promotion" component. This was because the promotional tools and corporate communication practices observable on websites tend to be more diverse and multifaceted than the other mix elements in the context of online environments.

As a result, a total of 19 criteria were identified, and these criteria along with their descriptions are presented in Table 1.

A two-step method has been applied in this study.

In the first phase, the official websites of the food companies that constitute the sample of the study, as listed in the ISO 500 list, were thoroughly examined. The information and downloadable documents on these websites were systematically evaluated according to the determined criteria. The presence or absence of these criteria on the websites of the companies was analyzed using a coding method.

In the second phase, a control analysis was performed. Criteria that were found to be absent on the websites in the first phase were re-examined for each site using the internal search function of Google. Thus, each website was analyzed twice according to the established criteria, ensuring that no criteria were overlooked and enabling a comprehensive investigation.

RESULTS AND DISCUSSION

When the criteria related to the product mix were examined, it was found that all companies except one included product categories on their websites. Companies that provided information on product features such as ingredients, nutritional values, and areas of use accounted for 83.3% of all companies. In this context, it can be seen that the vast majority of companies present various features of the products they sell on their websites. The proportion of companies that featured photographs of their products or images of their packaging on their websites was 90.2%. This indicates that most companies include product visuals as a marketing strategy. Similarly, 90.2% of the companies included various quality certificates, standards, or certifications related to their production processes or products. This strategy enables companies to build consumer trust by emphasizing that their products comply with certain quality standards. Thus, it is evident that the vast majority of companies value and include all four criteria related to the product mix on their websites, adopting a strategy of presenting them to consumers (Table 2).

Table 2. Product-Related Criteria

Product-Related Criteria	Yes	No	Total
Product Categories	101 (%99.0)	1 (%1.0)	102
Product Features	85 (%83.3)	17 (%16.7)	102
Product Images	92 (%90.2)	10 (%9.8)	102
Certificates and Certifications	92 (%90.2)	10 (%9.8)	102

When the criteria related to the price mix were examined, it was observed that the current situation differs significantly from the product mix. The proportion of websites that provided information about discounts and campaigns related to their products remained low at 19.6%. Among companies with an online sales platform, only 17.6% offered various types of payment options, allowing consumers to choose from different methods. Lastly, only 21.6% of the companies provided price information for their products on their websites, indicating that the vast majority prefer not to share this information online. In this regard, unlike the product category, the proportion of companies including price mix criteria on their websites remains considerably low (Table 3).

Table 3. Price-Related Criteria

Price-Related Criteria	Yes	No	Total
Discounts and Campaigns	20 (%19.6)	82 (%80.4)	102
Payment Options	18 (%17.6)	84 (%82.4)	102
Product Prices	22 (%21.6)	80 (%78.4)	102

When examining the place mix criteria, it was found that only 26.5% of companies provided information on dealers, distributors, sales points, or business partners through which consumers could access their products. In this respect, it was determined that only about one-quarter of the companies offer such information to consumers. The proportion of companies that sell products directly through their websites or redirect consumers to another company-owned sales platform was 20.6%. Based on these findings, it was concluded that the proportion of companies that include criteria related to the place mix on their websites also remains quite low (Table 4).

Table 4. Place-Related Criteria

Place-Related Criteria	Yes	No	Total
Dealers / Distributors / Sales Points / Business Partners	27 (%26.5)	75 (%73.5)	102
Online Sales / Platform Redirection	21 (%20.6)	81 (%79.4)	102

When the criteria related to the promotion mix were examined, it was observed that 84.3% of the companies shared announcements or news on their websites intended for customers, business partners, and the general public. A total of 31.4% of the companies published annual reports or similar detailed documents. It was identified that 100.0% of the companies provided contact information on their websites. Additionally, 47.1% of the companies included FAQ (Frequently Asked Questions) or similar informative sections to address consumer inquiries. All companies (100.0%) shared history or about information such as the company's history or profile. Regarding language options, 87.3% of the companies offered support in foreign languages in addition to Turkish. However, only 22.5% provided a newsletter subscription feature to inform customers about the company and its products. It was also found that 88.2% of the companies included social media redirects on their websites. Moreover, 60.8% shared information about their social responsibility or sustainability projects. Finally, 76.5% of the companies presented their vision, mission, and values, reflecting their institutional identity (Table 5).

Table 5. Promotion-Related Criteria

Promotion-Related Criteria	Yes	No	Total
Announcements/News	86 (%84.3)	16 (%15.7)	102
Annual Reports	32 (%31.4)	70 (%68.6)	102
Contact Information	102 (%100.0)	0 (%0.0)	102
Frequently Asked Questions (FAQ)/What You May Wonder	48 (%47.1)	54 (%52.9)	102
History/About	102 (%100.0)	0 (%0.0)	102
Language Options	89 (%87.3)	13 (%12.7)	102
Newsletter Subscription	23 (%22.5)	79 (%77.5)	102
Social Media Redirects	90 (%88.2)	12 (%11.8)	102
Social Responsibility / Sustainability Projects	62 (%60.8)	40 (%39.2)	102
Vision, Mission, Values	78 (%76.5)	24 (%23.5)	102

In this section, a classification was made for each company based on whether they included the aforementioned criteria on their websites, and the effectiveness of website usage in terms of marketing strategies was determined. In this classification, companies were awarded 1 point for each criterion they included on their websites. Thus, with a total of 19 criteria, the maximum score a company could achieve was 19. This scoring system enabled an objective evaluation of the companies' inclusion of the identified marketing criteria and allowed for a comparison of their performance.

Accordingly, companies were classified based on their total scores as follows: 0–3 points as "Very Low Effectiveness," 4–6 points as "Low Effectiveness," 7–10 points as "Moderate Effectiveness," 11–14 points as "High Effectiveness," and 15–19 points as "Very High Effectiveness." Based on this classification, no company was found to have very low or low effectiveness. It was determined that 32.4% of the companies demonstrated moderate effectiveness, 52.9% showed high effectiveness, and 14.7% exhibited very high effectiveness.

Therefore, it can be concluded that the companies utilized their websites with at least a certain level of effectiveness in terms of marketing strategies. This result is to be expected considering that the companies analyzed are among the largest in Turkey (Table 6).

Table 6. Marketing Effectiveness Results

Marketing Effectiveness Results	**Frequency**	**%**
0–3 points: Very Low Effectiveness	0	0.0
4–6 points: Low Effectiveness	0	0.0
7–10 points: Moderate Effectiveness	33	32.4
11–14 points: High Effectiveness	54	52.9
15–19 points: Very High Effectiveness	15	14.7
Total	102	100.0

The findings obtained indicate that companies focus on different elements of the marketing mix to varying degrees in their website development strategies. Considering all these findings, it is possible to discuss the potential reasons, disadvantages, and current areas for development in more detail.

In this context, the research findings show that the vast majority of companies include product categories (99.0%), product features (83.3%), product images (90.2%), and various quality certificates and certifications (90.2%) on their websites. This suggests that companies have largely adopted the criteria of product mix and developed strategies to present their products in detail to consumers. The significant presence of these criteria on the websites indicates that companies emphasize promoting their products, highlighting product quality, and informing consumers about the products. Information regarding product categories and features is generally presented in a manner that can be easily seen on the websites of the companies examined. However, it was found that some companies prefer to provide this information not directly on the website, but via downloadable product catalogs accessed through links. From a consumer experience perspective, this approach may make it more difficult for some users to access product information and limit direct interaction opportunities with the products. A more user-centered approach could be adopted, where product categories are both directly accessible on the websites and also available in downloadable formats on demand, which could be an important strategy for enhancing consumer satisfaction.

When evaluating the criteria related to the price mix, it was observed that a very low proportion of companies include information on discounts and campaigns (19.6%), payment options (17.6%), and product prices (21.6%) on their websites. The low inclusion of price-related criteria on websites could have various reasons. First, it is likely that companies prefer to keep their pricing strategies confidential to protect themselves from competition or gain a competitive advantage. Moreover, the variability and dynamic nature of pricing policies could make it difficult for companies to continuously share and update up-to-date pricing information on their websites. Therefore, companies may prefer not to share such information on their websites. Similarly, the lack of sufficient information on discounts and campaigns on websites could stem from various reasons. Some companies may find it challenging to continuously update this information due to the fact that campaigns and discounts are not permanent or are limited to specific periods, and they may prefer not to include them on their websites. Another possibility is that large companies, which sell their products through different retailers, may allow the prices, discounts, and campaign information to be determined and managed by these retailers rather than publishing this information on their own websites. This approach could be aimed at preventing confusion on the company's website by considering the dynamic nature of pricing and inter-store variability.

However, businesses may still benefit from being more transparent about price-related information. Sharing such information could increase customer trust and strengthen the brand's reliability. Additionally, regular announcements of campaigns and discounts could directly influence sales by meeting the expectations of the target audience. This could contribute to increased customer satisfaction and offer an opportunity for effective campaign management through websites. As a result, companies could reach a potential customer base more effectively and gain a competitive advantage by sharing such information.

When evaluating the criteria related to the place mix, it was observed that companies include information on dealers, distributors, sales points, and business partners (26.5%) and online sales (20.6%) to a low extent. This indicates that companies adopt a limited approach to sharing their place strategies and conducting online sales on their websites. Various reasons for this can be considered. Since the examined companies are among the largest food and beverage companies in Turkey, it is possible that they do not include this information on their websites because they can easily reach consumers through other means. However, the absence of distribution strategy information on websites may lead to various disadvantages for companies. Consumers who are looking for a product but cannot access information about sales points may lose the opportunity to purchase the product

and may turn to alternative products. This could negatively impact customer satisfaction and potentially lead to sales losses and a loss of competitive advantage for companies.

Similarly, the fact that only a limited portion of companies conduct online sales through their websites is an important factor that could lead to significant losses for companies. As e-commerce becomes more widespread, consumers expect to have easy and fast access to products and services. However, the limited availability of online sales options may fail to meet these expectations and reduce the competitive strength of companies in the digital market. When online sales are limited, especially consumers who do not have physical access to certain areas may experience difficulty accessing relevant products and may tend to switch to alternative brands. This is another significant disadvantage for companies. On the other hand, online sales platforms provide valuable data for analyzing customer behavior and preferences. The lack of access to this data could make it difficult for companies to make strategic decisions in their marketing and product development processes. Therefore, providing information about distribution strategies on websites is considered an important strategic opportunity for enhancing consumer satisfaction and increasing companies' competitive advantage.

When evaluating the criteria related to the promotion mix, it was observed that some criteria were prominently included on websites, while others were represented to a very low extent.

84.3% of companies include various announcements or news that they wish to share on their websites. These are often found under headings like "Announcements" or "News," but some websites also feature sections titled "Blog" or "Press Room." In these sections, current news and announcements about the business or its activities can be found, and some businesses also regularly share monthly press releases in these sections.

A limited portion of companies (31.4%) have shared their annual activity reports on their websites. However, since annual activity reports are important documents that provide a detailed summary of a company's performance, strategic goals, and financial status throughout the year, sharing these reports with the public can enhance the perception of reliability and professionalism, especially among investors, business partners, and informed consumers. In this regard, this area is considered to have room for improvement.

It was determined that all companies included their contact information (address, phone number, email, etc.) on their websites. This indicates that companies adopt a customer-focused approach and aim to establish easy and accessible communication with consumers.

It has been determined that nearly half of the companies (47.1%) include a section on their websites under titles such as “Frequently Asked Questions” or “What You May Wonder” where they address commonly asked questions from consumers regarding the products or the company. It was also observed that similar sections appear under different titles on some business websites, such as “Useful Information,” “Information for Consumers,” or “Did You Know?”. Including such sections on company websites facilitates consumers’ access to various types of information about the products and the company. Providing detailed information in these sections about food storage conditions, consumption guidelines, allergen information, product ingredients, additives, and production processes not only informs consumers about critical issues but also serves as a factor that enhances the perceived reliability of the brand, benefiting the company.

It has also been identified that all companies include a section on their websites—titled “History” or “About Us”—that provides information about the company, such as its background and areas of activity. These sections serve as a valuable source for new consumers to get to know the brand and function as a tool to strengthen brand loyalty among existing consumers. Such content is important because it contributes to a more effective digital presence for companies and forms a significant part of their corporate communication strategies.

A large portion of companies (87.3%) offer at least one foreign language option on their websites. The provision of foreign language options is particularly important for companies engaged in export activities. This not only makes it easier to reach potential foreign customers but also increases the accessibility of the business on an international level. At the same time, multilingual websites can strengthen the brand's professional image and help it gain a stronger position in the global competitive environment. Therefore, it is clear that the companies examined place significant importance on these strategies. However, in some websites, although there are buttons leading to foreign language options, these buttons do not work, and foreign language pages are not available. This is a notable deficiency for the companies.

A limited portion of companies (22.5%) offers visitors the option to subscribe to a newsletter. The low number of companies offering this option indicates that they do not adequately utilize e-newsletters in their digital marketing and customer relationship management strategies. One reason for this could be that companies prefer to focus more on social media platforms or consider e-newsletters to be less effective. However, e-newsletter subscriptions are a valuable tool for maintaining direct communication with consumers and regularly informing them about products, campaigns, and updates. Given this, companies' low participation in this area suggests they have not fully utilized the opportunity to establish a regular and effective connection with their target audience.

It was found that a large majority of companies (88.2%) include links to their various social media accounts (Twitter, Instagram, Facebook, etc.) on their websites. However, some companies, despite having social media accounts, did not include links to these accounts on their websites. Additionally, some companies did include links to social media accounts, but these links did not work. These two situations are significant deficiencies.

It was determined that 60.8% of companies provide information on their websites about social responsibility and sustainability projects they have carried out or completed. Some companies, despite conducting various social responsibility projects, do not announce them on their websites, which is a significant deficiency. Other companies, although they state their social responsibility or sustainability policies or principles on their websites, do not share the projects or activities they have carried out under these principles. Addressing these deficiencies by effectively announcing social responsibility and sustainability projects and transparently sharing their practices could strengthen their corporate reputation and positively impact consumer preferences.

A large majority of the companies (76.5%) have shared information on their websites regarding their vision, mission, and values. It was observed that these statements appear on the homepage of some companies, in a separate section on others, and within published activity reports in some cases. It is important that these vision, mission, and value statements are positioned in a way that is easily accessible to consumers. Nevertheless, this situation indicates that a significant portion of businesses have taken a strategic step toward introducing themselves to their target audiences and establishing their brand identity.

CONCLUSION

In general, it has been observed that companies implement a more comprehensive and effective strategy on their websites in terms of product mix criteria. However, the websites contain limited information regarding price and place mix criteria. As for promotion-related criteria, while some areas provide more detailed information, in other areas the information offered on company websites remains quite insufficient.

In this regard, although the inadequacy of some criteria in terms of content and strategy could partly be attributed to company preferences, strategic choices, or the challenges of continuously updating dynamic data, it is clear that the significant lack of certain critical elements poses a disadvantage for the companies from a marketing strategy perspective. Among these, the most important areas were online sales (20.6%), newsletter subscriptions (22.5%), annual reports (31.4%), and frequently asked questions (47.1%). These figures highlight a clear potential for improvement in the websites of food companies.

Online sales have become an integral part of companies' marketing strategies in today's increasingly digital world. However, the research findings indicate that a large majority of company websites (79.4%) do not offer online sales options. Yet, enabling online sales through their websites or redirecting visitors to their own e-commerce platforms not only provides companies with an opportunity to generate revenue, but also plays a critical role in enhancing brand awareness and fostering a stronger connection with consumers. In this context, companies that lack an online sales option on their websites miss the chance to present their products directly to potential customers and complete sales. This situation may prevent website visitors from fulfilling their immediate purchasing intentions and could potentially redirect them to other sales platforms or competing companies. Considering that these businesses are among the largest food companies in Turkey, it would be feasible for them to establish such infrastructure. Therefore, offering online sales through corporate websites emerges as a factor that companies should seriously consider.

Newsletter subscription is a highly valuable tool that can be featured on the websites of food companies. It provides companies with the opportunity to communicate directly and regularly with their target audience. This tool is an effective way to build brand awareness, foster customer loyalty, and engage with potential customers. Moreover, through these subscriptions, companies can quickly share updates about product or service innovations, promotional campaigns, or industry developments. However, the analysis reveals that only 22.5% of the companies offer users the option to subscribe to an e-newsletter. This shortcoming indicates that many businesses are missing the opportunity to maintain regular contact with their potential customer base, making it a clearly visible area for improvement and growth.

The fact that only a limited portion of companies (31.4%) include annual reports on their websites prevents consumers who wish to gain more detailed information about the company from accessing such data. These reports are important not only for investors but also for consumers. When consumers seek to trust a company and build long-term relationships with it, they expect to learn more about its operations. In this regard, publishing activity reports on the websites of Turkey's largest food companies appears to be an important necessity.

The Frequently Asked Questions (FAQ) section is a vital tool that enhances customer satisfaction by addressing the most common inquiries consumers have about a product or company. Given that food products are directly related to consumer health, it is crucial for consumers to have easy access to accurate and

comprehensive information about them. When purchasing food items, consumers not only consider price and quality but also seek essential details such as how to consume, cook, or store the product. However, it has been identified that 52.9% of the examined companies do not provide such a section on their websites. This indicates a significant shortcoming. For consumers, the absence of this section means losing the opportunity to easily access fundamental product information. In the food industry, especially for conscious consumers, not being able to obtain critical information such as cooking methods, storage instructions, and allergen content may result in a negative experience, potentially affecting their purchasing decisions. Such a situation can lead to customer dissatisfaction, undermine trust in the brand, and ultimately cause customer loss. Therefore, the FAQ section should go beyond merely offering basic product information; it should serve as a resource that enables consumers to enjoy a healthy and safe consumption experience. From the companies' perspective, the absence of this section may leave website visitors with unmet informational needs. This can drive potential customers away, as users who cannot easily find the information they are looking for may seek alternative products. Furthermore, the lack of such information may create an impression that the brand lacks professionalism. This shortcoming could damage brand reputation and lead to decreased sales in the long term. Additionally, this deficiency may increase the workload of customer service departments due to more frequent inquiries. In conclusion, developing these sections thoroughly would not only improve the consumer experience but also help companies deliver faster and more effective services to their customers.

In conclusion, an overall assessment reveals that food companies generally demonstrate a comprehensive strategy in terms of product assortment on their websites, while certain shortcomings and areas for improvement have been identified in the criteria related to price, place, and promotion. Considering the increasing competition in the food sector, the growing importance of digital marketing, and the evolving consumer expectations, restructuring company websites to address these deficiencies could provide significant advantages for companies.

Declaration of interests

The author declares that there is no conflict of interest.

Author Contributions

The author is solely responsible for the conception, design, data curation, formal analysis, investigation, methodology, software, and writing of this manuscript, including both the original draft and subsequent revisions.

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Original Article

The Effect of Aronia Pulp Addition Instead of Wet Brewers Grain Pulp in Total Mixed Ration on *In Vitro* Gas Production Technique Parameters

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ABSTRACT

In this study, the effect of adding aronia pulp instead of wet brewers grain pulp to dairy cattle rations on *in vitro* gas production parameters was examined. The materials of the study consisted of total mixture ration (R1) based on maize silage with a DM content of 52.77%. Two rations were formed by adding 1% (R2) and 2% (R3) aronia pomace to the prepared ration mixture (R1) instead of wet brewers grain pomace. In the study in which *in vitro* gas production technique was used, gas production (GP) and methane (CH_4) production of the groups were determined. Organic matter digestibility (OMD), metabolic energy (ME) and net energy lactation (NEL) values were calculated with the amount of GP obtained at 24th hour of incubation. The number of protozoa, pH values and viscosity were determined as parameters related to rumen fluid. Addition of aronia pulp to the ration decreased the amount of GP and CH_4 ($P<0.05$). As the amount of aronia pulp in the ration increased, rumen pH value increased ($P<0.012$). At the initial stage of incubation, the number of protozoa in rumen fluid was $0.63x10^5$, whereas at 48th hour of incubation, the number of protozoa ranged between $0.94\text{-}1.25 x10^5$. There was no statistical difference between the groups in viscosity of rumen fluid ($P>0.05$). As a result, it was determined that the addition of aronia pulp to the ration increased the digestibility of the feed and contributed positively to rumen microbiota.

Key words: Digestibility, Methane, Pulp, Viscosity

Toplam Rasyon Karışımına Yaş Bira Posası Yerine Aronya Posası İlavesinin *İn Vitro* Gaz Üretim Tekniği Parametreleri Üzerine Etkisi

ÖZ

Bu çalışmada, süt sığırı rasyonlarına yaş bira posası yerine aronya posası ilavesinin *in vitro* gaz üretim parametrelerine olan etkisi incelenmiştir. Araştırmanın materyalini %52.77 KM içeriğine sahip mısır silajına dayalı toplam rasyon karışımı (R1) oluşturmuştur. Hazırlanan rasyon karışımına (R1) yaş bira posası yerine %1 (R2) ve %2 (R3) oranında aronya posası ilave edilerek iki rasyon oluşturulmuştur. *In vitro* gaz üretim tekniğinin kullanıldığı çalışmada, grupların gaz üretimi (GÜ), metan (CH_4) üretimi belirlenmiştir. İnkübasyonun 24. saatinde elde edilen GÜ miktarları ile organik madde sindirilebilirliği (OMS), metabolik enerji (ME) ve net enerji laktasyon (NEL) değerleri hesaplanmıştır. Rumen sıvısına ilişkin parametreler olarak, protozoa sayısı, pH değerleri ve viskozitesi belirlenmiştir. Rasyonlara aronya posası ilavesi GÜ ve CH_4 miktarını azaltmıştır ($P<0.05$). Rasyondaki aronya posası oranı arttıkça rumen pH'sı yükselmiştir ($P<0.012$). İnkübasyonun başında rumen sıvısındaki protozoa sayısı $0.63x10^5$ iken, inkübasyonun 48. saatinde protozoa sayısı $0.94\text{-}1.25 x10^5$ arasında değişmiştir. Gruplar arasında rumen sıvısı viskozitesi açısından istatistiksel bir fark bulunmamıştır ($P>0.05$). Sonuç olarak, rasyona aronya posası ilavesinin yemin sindirebilirliğini artırdığı ve rumen mikrobiyatına ise olumlu katkı sağladığı belirlenmiştir.

Anahtar kelimeler: Sindirilebilirlik, Metan, Posa, Viskozite

INTRODUCTION

The demand for more sustainable animal products is raising interest in the use of byproducts of the feed industry in animal nutrition. The most potentially interesting in this respect are the pulps from the processing of fruit and vegetables, which are by-products of the food industry. Pulps are the pressing residues left after the production of fruit and vegetables. They consist of seeds, stems and skins in varying amounts. Millions of tonnes of pulp are produced worldwide every year and need to be discarded (Shalini and Gupta, 2010). Waste disposal of pulp is a major problem and is also very costly. In a study from the United States of America (USA), it was found that an estimated USD 10 million is spent annually to waste the pulp produced from apples alone (Giller et al., 2022). Disposal of pulp is a major problem and also very costly. In a study conducted in the United States of America (USA), it was found that an estimated USD 10 million is spent annually to dispose of the pulp produced from apples alone (Giller et al., 2022). The high amounts of sugars, fibre, protein, lipids and bioactive compounds in pulps cause environmental pollution if the pulps are disposed of in landfills, while not using these nutrients is a waste of resources (Osorio et al., 2021). Therefore, pulps are partially processed in secondary applications such as extraction of pectin and bioactive compounds for supplements in human nutrition, production of alcoholic beverages and use as fertiliser (Shalini and Gupta, 2010; Varzakas et al., 2016). In addition, pulps are also used for energy production in biogas reactors (Shalini and Gupta, 2010). A small portion of these valuable by-products is utilised as animal feed and reintroduced into the food chain (Giller et al., 2022). The number of studies investigating the effects of feeding pulps on productivity, product quality, greenhouse gas emissions, nitrogen excretion and ruminant health has increased in recent years (Ülger et al., 2020; Canbolat, 2022). Some researchers have reported that pulps, especially those from dark red fruits, can potentially reduce CH_4 emissions and ammonia excretion as they contain large amounts of polyphenols such as tannins, thus reducing liver stress and environmental pollution (Patra and Saxena, 2011; Naumann et al., 2015; Singla et al., 2021; Koç et al., 2024). One of the materials with high antioxidant capacity is aronia fruit. Aronia (*Aronia melanocarpa*) fruits contain many bioactive compounds, including anthocyanins, carotenoids, fatty acids, flavonoids, phenolic compounds, and vitamins. Nowadays, aronia is also grown in Eastern European countries and Russia, where it is used in the production of homemade or commercial fruit juices, jams, fruit teas, wine, and natural food colourings (Yilmaz et al., 2021). Black aronia (*Aronia melanocarpa*) species contain higher levels of anthocyanins than purple (*Aronia prunifolia*) or red aronia (*Aronia arbutifolia*) species, while red and purple aronia are more rich in phenolic acids and proanthocyanins. In addition to the antioxidant effect of aronia fruits, they also have antiviral, antibacterial, antidiabetic and anti-inflammatory effects (Jurikova et al, 2017). Aronia fruit contains more than 40 essential compounds which are dominated by benzaldehyde cyanohydrin, hydrocyanic acid and benzaldehyde. The most abundant flavonoids contained in aronia are anthocyanins and procyanidins consisting mainly of (-) epicatechin (Kokotkiewicz et al., 2010; Koç, 2023). The main flavanols in aronia content are procyanidins. The amount of procyanidins varies between 0.66% and 5.18% by dry weight (Wu et al., 2004). The presence of anthocyanins is one of the most important factors determining the antioxidant capacity of the plant. Anthocyanins in aronia fruits have a high phenolic content, with a concentration range ranging from 0.60 to 2.00% by dry weight. Total polyphenol content is 1752 mg per 100 g dry weight. The anthocyanin content is 1480 mg per 100 g dry weight, and the proanthocyanidin concentration is 664 mg per 100 g fresh weight. These values related to antioxidant capacity, are among the highest values measured in plants to date (Kokotkiewicz et al., 2010). The number of studies on the use of aronia pulp in animal nutrition was found to be limited. In the present study, the effects of adding aronia pomace to the total mixture ration(TMR) at different ratios instead of beer pomace on *in vitro* gas production parameters were investigated.

MATERIALS AND METHODS

Material

The aronia pulp (AP) used in the study was obtained from Tekirdağ Viticulture Research Institute. Wet brewers grain pulp (WPGP) was obtained from a private dairy farm. The fresh AP and WBGP were taken in fresh form and transferred to the laboratory of the Department of Animal Science, Tekirdağ Namık Kemal University.

Experimental Dairy Cow Rations for *In Vitro* Trial

A total mixed ration (R1) was formed from maize silage, wheat straw, alfalfa hay, vetch hay, wet brewers grain pulp, grain maize, and milk feed. Three rations were formed by adding AP at rates of 1% (R2) and 2% (R3) to this control group TMR. The control group is R1 ration. R2 ration was used to examine the effect of using fresh beer pulp and aronia pulp together. R3 ration was created to examine the effect of using aronia pulp instead

of fresh beer pulp. In the study, the feed ingredients used in the preparation of the rations and the contents and chemical composition of the rations prepared using these feed ingredients are given in Table 1.

Table 1. Ingredients and composition of the TMR (%)

Feed	R1 (%)	R2 (%)	R3 (%)
Corn silage	59.76	59.76	59.76
Wheat straw	2.39	2.39	2.39
Vetch	4.78	4.78	4.78
Alfalfa	11.95	11.95	11.95
Wet brewers grain pulp	2.00	1.00	0.00
Aronia pulp	0.00	1.00	2.00
Maize	4.78	4.78	4.78
Concentrated feed	14.34	14.34	14.34
DM	52.77	52.98	53.20
OM	85.11	85.12	85.12
CA	6.42	6.41	6.40
CP	13.22	13.05	12.87
EE	3.40	3.34	3.28

DM: Dry matter, OM: Organic matter, CA: Crude ash, CP: Crude protein, EE: Ether extract

In calculation of the nutrient requirements of the rations, the annual average yield of the dairy cattle was taken. Rations were prepared according to NRC (2001) by considering the daily energy and nutrient requirements of 51-month-old dairy cattle weighing 600 kg, giving 9.000 lactation/kg milk and having 3.5% milk fat.

Chemical Analysis

Dry matter (DM), crude ash (CA), crude protein (CP) and ether extract (EE) analyses of the feeds were performed according to the method reported in AOAC (2006). Feed samples used in the analyses were ground in a mill with a sieve diameter of 1 mm. The feeds used in the experiment were analysed in 3 replicates. The DM contents of the feeds were determined by drying in an oven at 65 ^{o}C overnight and the CA contents were determined by burning in an oven at 550 ^{o}C for 6 hours. Kjeldahl method was used for CP analysis and Ether Extraction method was used for EE analysis.

Determination of In Vitro Gas Production Parameters

The gas production technique reported by Menke et al. (1979) was used to determine *in vitro* gas production values. Rumen fluid was taken from 2-year-old Holstein cow slaughtered in the slaughterhouse, kept the temperature constant between 38-40 ^{o}C in a thermos, and brought to the laboratory quickly. The solid part remaining in the rumen fluid was separated by filtration with sterile 4-layer cheesecloth and brought brought to a suitable form for analysis. 200 mg of samples and standard feed were placed in 100-ml glass injectors, and 30 ml of rumen fluid/buffer solution (½) was added. The glass injectors were kept in the incubation cabinet at 39 ^{o}C for 48 hours, and the gas values at 3, 6, 12, 24, and 48 hours were measured. The gas values obtained at the 24th hour of incubation were corrected according to the standard feed. *In vitro* organic matter digestion (OMD), metabolic energy (ME), and net energy lactation (NE_L) values were calculated. Methane (CH_4) content was measured by a gas detector at the 24th hour of incubation. At the beginning and 48th hour of incubation, rumen pH values were measured with a digital pH metre.

$$ME = 2.2 + 0.136 \times GP + 0.0057 \times CP + 0.00029 \times EE^2$$
$$NE_L = 0.1149 \times \text{GP} + 0.0054 \times \text{CP} + 0.0139 \times \text{EE} - 0.0054 \times \text{CA} - 0.36$$
$$OMD = 14.88 + 0.889 \times GP + 0.45 \times CP + 0.0651 \times CA$$

GP: 24 h gas production amount (ml/200 mg); CP: Crude protein (DM%) in feed samples; EE: Ether extract (DM%) in the feed samples; CA: Crude ash content in feed samples (DM%). ME; Metabolic energy (MJ/kg, DM), NEL; Net energy lactation (MJ/kg, DM), OMD; *In vitro* organic matter digestion (g/100g, DM).

Protozoa Count

For protozoa counting, 1 ml of rumen fluid taken at the beginning and 48th hour of incubation was mixed with 9 ml of protozoa counting solution (0.6 g methyl green, 8 g NaCl, 100 ml 37% formaldehyde in a 1 liter flask and topped up with distilled water to the 1000 ml line). Using light microscopy, the number of protozoa per large square (16 medium-sized squares) was determined on a Thoma slide (depth: 0.100 mm, small square area: 0.0025 mm^2). The formula is used to calculate the number of protozoa per milliliter of rumen fluid based on microscopic counts: (Harmeyer, 1965).

$$P = \frac{N.F * D.R * U.V}{A} * 1000$$

P: Number of protozoa in 1 ml of rumen fluid
N.F: Number found (the actual number of protozoa counted)
D.R: Dilution ratio (1/10)
U.V: Unit volume (Volume of the smallest unit, 1/4000 mm^3)
A: Protozoan counting area (256 small squares)

Viscosity Density

Viscosity density test was performed to investigate the relationship between rumen viscosity and feed degradation in the rumen.The NDJ-1 Rotational Viscometer device was used to determine the viscosity density of rumen fluids. Rumen fluids obtained at the beginning and 48th hour of incubation were filtered on filter paper and centrifuged at 5000 rpm for 10 minutes. Density was calculated by taking the upper liquid part in the centrifuge tube. The dynamic viscosity (η) of rumen fluids whose viscosity was measured at a constant temperature of 24 ^{o}C was determined. The kinematic viscosity (v) was calculated with the formulas given below (Erten et al., 2023a).

Dynamic viscosity (mPa.s) = Coefficient (C) x Reading on the dial (Deflection angle) (a)

$$\eta = C \times a$$

Dynamic viscosity (mPa.s) = Kinematic viscosity (mm^2/s) x Density at the temperature when determining the kinematic viscosity (g/cm^3) (p)

$$\eta = v \times p$$

Statistical Analysis

Statistical analyses of the data obtained as a result of the analysis were made in the SPSS 27 package program. In the statistical evaluation of the data, a one-way analysis of variance was used to determine the difference between groups, and Tukey's multiple comparison test was used to compare group effects. Pearson for the determination of the relationship between the parameters correlation analysis test was performed (Genç and Soysal, 2018).

RESULTS and DISCUSSION

Results

The nutrient values of aronia pulp and wet brewer grain pulp used in the study are presented in Table 2.

Table 2. Nutrient values of aronia pulp and wet brewers grain pulp (DM%)

Parameters	AP	WBGP
DM	47.11	25.67
CA	2.53	3.66
CP	7.47	25.25
EE	3.97	10.00

AP: Aronia pulp, WBGP: Wet brewer grain pulp, DM: Dry matter, CA: Crude ash, CP: Crude protein, EE: Ether extract

The DM (47.11-25.67%), CA (2.53-3.66), CP (7.47-25.25) and EE values (3.97-10.00) of AP and WPGP were determined in DM%. While the DM value of aronia pulp was higher than WPGP, the CA, CP and EE values of WPGP were higher than AP.

In Vitro Gas Production

The results of the analyses of *in vitro* gas production of the rations are given in Table 3. The amounts of GP formed by AP and WPGP at the 48th hour of incubation were determined as 61.09 and 47.90 ml, respectively. The highest GP up to the 48th hour of incubation was found in the group supplemented with 2% Wet brewer grain pulp (61.54 ml). The combined use of WPGP and AP decreased the GP (52.20 ml). According to the data obtained, the CH_4 content of the rations varied between 6.56-11.51 ml. The highest CH_4 content was found in the group supplemented with 2% WPGP, while the lowest CH_4 content was found in the group supplemented with 1% AP and 1% WPGP. The combined use of AP and WPGP decreased the CH_4 content of the ration (P<0.001). The amounts of CH_4 produced by AP and WPGP at the end of 24 hours incubation were 6.75 and 10.25 ml, respectively.

Table 3. Aronia pulp and wet brewers grain pulp supplementation on *in vitro* gas production

Pulp	Ratio%	Time (Hour)					
		3	**6**	**12**	**24**	**48**	**CH_4**
AP		7.32	13.91	30.61	55.09	61.09	6.75
WBGP		5.83	11.09	24.39	43.90	47.90	10.25
AP	0	7.78 a	14.78 a	32.52 a	58.53 a	61.54	11.51 a
	1.0	6.41 b	12.17 b	26.78 b	48.20 b	52.20	6.56 c
	2.0	6.86 ab	13.04 ab	28.69a b	51.65 ab	55.65	9.83 b
WBGP	0	6.86 ab	13.04 ab	28.69a b	51.65 ab	55.65	9.83 b
	1.0	6.41 b	12.17 b	26.78 b	48.20 b	52.20	6.56 c
	2.0	7.78 a	14.78 a	32.52 a	58.53 a	61.54	11.51 a
SEM		0.245	0.465	1.022	1.840	1.710	0.819
				P			
Pulp		0.230	0.230	0.230	0.230	0.293	0.065
Ratio %		0.047	0.047	0.047	0.047	0.059	0.000
Pulp*Ratio		0.230	0.230	0.230	0.230	0.293	0.023

$^{a–c}$: The difference between groups with different letters in the same column is statistically significant. AP: Aronia pulp, WBGP: Wet brewer grain pulp, SEM: Standard errors of mean

The results of the analyses of OMD ME and NEL values of the rations are shown in Table 4.

Table 4. Aronia pulp and wet brewers grain pulp supplementation on *in vitro* OMD, ME and NEL values

Pulp	Ratio %	OMD	ME	NEL
AP		68.88	13.06	6.02
WBGP		67.66	19.59	6.46
	0	77.06 a	16.11 a	6.57 a
AP	1.0	67.79 b	14.63 b	5.51 b
	2.0	70.77 ab	15.02 ab	5.86 ab
	0	70.77 ab	15.02 ab	5.86 ab
WBGP	1.0	67.79 b	14.63 b	5.51 b
	2.0	77.06 a	16.11 a	6.57 a
SEM		1.648	0.261	0.188
		P		
Pulp		0.220	0.174	0.214
Ratio %		0.047	0.048	0.047
Pulp*Ratio		0.220	0.174	0.214

$^{a–b}$: The difference between groups with different letters in the same column is statistically significant. Aronia pulp, WBGP: Wet brewer grain pulp, OMD: Organic matter digestibility (g/100g, DM), ME: Metabolic energy (MJ/kg, DM), NEL: Net energy lactation (MJ/kg, DM), SEM: Standard errors of mean.

According to the results obtained, OMD values of the rations varied between 67.79-77.06 g/100g, DM. The highest OMD value was found in the group supplemented with 2% WPGP, while the lowest OMD value was found in the group supplemented with 1% AP and 1% WPGP. The difference between the groups was found statistically significant (P<0.05). The ME values of the rations varied between 14.63-16.11 MJ/kg, DM. The highest ME value was found in the group supplemented with 2% WPGP, while the lowest OMD value was found in the group supplemented with 1% AP and 1% WPGP. The difference between the groups was found statistically significant (P<0.05). ME values of aronia pulp and wet brewers grain were 13.06 and 19.59 MJ/kg, DM, respectively. The NEL values of the rations varied between 5.51-6.57 MJ/kg, DM. The highest NEL value was found in the group supplemented with 2% wet brewers grain, while the lowest NEL value was found in the group supplemented with 1% AP and 1% WPGP. The difference between the groups was found statistically significant (P<0.05).

Rumen Fluid Parameters

The rumen fluid parameters of the rations are given in Table 5. The pH value of the rumen fluid was measured as 7.20 at the beginning of the incubation, and it changed between 6.82-7.15 at the 48th hour of incubation. The highest pH value was found in the group supplemented with 2% AP, while the lowest pH value was found in the group supplemented with 2% WPGP (P<0.001). As the dose amount of AP increased, rumen pH value increased (P<0.012). Figure 1. Images of protozoa in rumen fluid under optical microscope (x40).

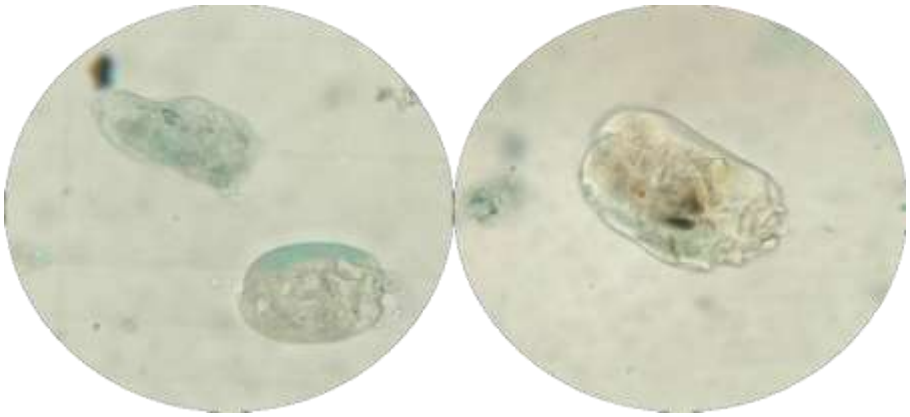

Figure 1. Images of protozoa in rumen fluid under optical microscope (x40)

At the beginning of the incubation, the number of protozoa in the rumen fluid was 0.63x10^{5}, while the number of protozoa ranged between 0.94-1.25x10^{5} at the 48th hour of incubation. The highest number of protozoa was observed in AP supplemented groups.

Table 5. Aronia pulp and wet brewers grain pulp supplementation on *in vitro* ruminal fluid parameters

Pulp	Ratio%	pH0	pH48	Protozoa0	Protozoa48	Vizcosity0	Vizcosity48
AP		7.20	6.99	0.63	1.88	0.206	0.203
WBGP		7.20	7.09	0.63	1.25	0.206	0.321
	0	7.20	6.82 c	0.63	0.94 b	0.206	0.436
	1.0	7.20	7.07 b	0.63	1.25 a	0.206	0.370
AP	2.0	7.20	7.15 a	0.63	1.25 a	0.206	0.402
	0	7.20	7.15 a	0.63	1.25 a	0.206	0.402
	1.0	7.20	7.07 b	0.63	1.25 a	0.206	0.370
WBGP	2.0	7.20	6.82 c	0.63	0.94 b	0.206	0.436
SEM			0.047		0.051		0.019
				P			
Pulp			0.001		0.000		0.698
Ratio			0.012		0.000		0.320
Pulp*Ratio			0.001		0.000		0.698

$^{a–c}$: The difference between groups ith different letters in the same column is statistically significant. AP: Aronia pulp, WBGP: Wet brewers grain pulp, Protozoa count: x10^{5}, Viscosity: (mm^{2}/s), SEM: Standard errors of mean

At the beginning of the incubation, rumen fluid viscosity value was determined as 0.206 mm^{2}/s. At the 48th hour of incubation, this value was determined as 0.370-0.436 mm^{2}/s. There was no statistical difference between the groups in terms of rumen fluid viscosity (P>0.05).

Discussion

The demand for more sustainable production of foods of animal origin is increasing interest in the utilisation of food industry by-products in animal nutrition. The most potentially interesting in this respect are the pulps from the processing of fruit and vegetables, which are by-products of the food industry. Pulps are the pressing residues left after the production of fruit and vegetables. They consist of seeds, stems, and skins in varying proportions. Millions of tonnes of pulp are produced worldwide every year and need to be disposed of (Shalini and Gupta, 2010). Disposal of pulps is a big problem and also very costly. In a study conducted in the United States of America (USA), it was found that an estimated USD 10 million is spent annually to dispose

of the pulp produced from apples alone (Giller et al., 2022). The high amounts of sugars, fibre, protein, lipids, and bioactive compounds present in pulps cause environmental pollution if the pulps are disposed of in landfills, while not using these nutrients is a waste of resources (Osorio et al. 2021) Therefore, pulps are partially processed for secondary applications such as the extraction of pectin and bioactive compounds for supplements in human nutrition, the production of alcoholic beverages, and use as fertilizer (Shalini and Gupta, 2010; Varzakas et al., 2016). Pulps are also used for energy production in biogas reactors (Shalini and Gupta, 2010). A small portion of these valuable by-products is utilised as animal feed and reintroduced into the food chain. The high crude cellulose content makes pulp an interesting component for ruminant nutrition (Giller et al., 2022). The number of studies investigating the effects of feeding pulps on productivity, product quality, greenhouse gas emissions, nitrogen excretion and ruminant health has increased in recent years (Chedea et al., 2017; Ülger et al., 2020; Singla et al., 2021; Canbolat, 2022, Koç et al., 2024). Some researchers have reported that pulps, especially those obtained from dark red fruits, can potentially reduce CH_4 emissions and ammonia excretion as they contain large amounts of polyphenols such as tannins, thus reducing liver stress and environmental pollution (Patra and Saxena, 2011; Naumann et al., 2015; Singla et al., 2021; Koç et al., 2024). In this study, the addition of aronia pulp to the total mixed raiton increased rumen degradation due to its high antioxidant content, and the decrease in the amount of CH_4 in the rumen may be due to its antioxidant capacity. The high amount of CP in the wet brewer's grain in the ration caused an increase in the amount of CH_4 by proteolysis in the rumen. When feeds are broken down in the rumen, volatile fatty acids (VFA) are formed in the environment, these fatty acids increase the acidity of the environment by decreasing the pH level in the rumen fluid (Erten et al., 2023b). While this acidity was observed in wet brewers grain in the study, aronia pulp improved the rumen pH value thanks to its antioxidant level.

The content of the product obtained also plays an important role in the studies conducted with pulps. As a matter of fact, in a study conducted with apple or carrot pulps, it was reported that these pulps may adversely affect rumen fermentation and increase CH_4 production because they are also rich in sugar (Bao and Chang, 1994). In a study conducted by Giller et al. (2022), it was determined tha aronia pulp had lower CH_4 amounts than lemon, orange and mandarin pulps. The result of the research supports the studies on this subject. In the study, total GP values of aronia (61.09 ml) and wet brewers grain (47.90 ml) were determined after incubation. The high amount of GP obtained when aronia pulp is used alone in the ration is due to its high antioxidant level (Denev et al., 2018). The antioxidant level of aronia increases rumen degradation and suppresses CH_4 producing bacteria. However, when aronia pulp is added to the ration, it prevents the breakdown of proteins together with the amount of tannins it contains, which causes a decrease in the GP amount of the ration. In similar studies conducted on this subject, the GP amounts of lemon, orange and tangerine pulp silages obtained at the end of 24 hours of incubation were determined as 74.00, 77.00 and 74.67 ml, respectively (Ülger et al., 2020). In a study conducted with apple pulp, it was reported that the amount of GP obtained after 24 hours of incubation was 43.86 ml (Canbolat, 2022), and in a study conducted with white mulberry pulp silage, it was reported that the amount of GP obtained after 24 hours of incubation was 30.18 ml (Köksal et al., 2021). In a study conducted with sugar beet pulp silage, it was determined that the amount of GP formed after 24 hours of incubation was 47.05 ml (Kılıç and Sarıçiçek, 2010), In the study conducted with pomegranate pulp silage, it was determined that the amount of GP produced at the end of 24 hours of incubation was 41.83 ml. In terms of the amount of gas production, it was determined that aronia pulp was higher than apple pulp, mulberry pulp, sugar beet pulp and pomegranate pulp silages. According to the results obtained from the study, the OMD values of the rations varied between 67.79-77.06 g/100g, DM. In similar studies on pulps, the OMD value of sugar beet pulp was determined as 62.35% Kılıç and Sarıçiçek (2010), Canbolat et al. (2014) reported that the OMD value of pomegranate pulp was 51.60%. Köksal et al. (2021) determined the OMD value of white mulberry pulp as 53.27%. In a study conducted by Taasoli and Kafilzadeh (2008) in sheep, *in vitro* organic matter digestibility (IVOMD) values of 150 and 300 g kg^{-1} dried apple pulp addition to the ration were found to be 665 and 686 g kg^{-1}, respectively. Mirzaei-Aghsaghali et al. (2011) determined that IVOMD was 715 g kg^{-1} when dried apple pulp was added to the ration. Giller et al. (2022) found that aronia pulp also increased IVOMD compared to lemon, orange and mandarin pulp. The researchers determined the IVOMD value of aronia pulp as 728 g kg^{-1}.

The results of the research were similar to the studies on this subject. The ME values of aronia pulp and wet brewers grain were determined as 13.06 and 19.59 MJ/kg, DM, respectively. Although the amount of GP was higher in aronia pulp due to rumen degradation, the higher amount of CP in wet brewers grain caused it to be higher in terms of ME value. In a study, ME and NE_L values of grape pulp silage were found as 7.71 and 4.29 MJ/kg DM (Özdüven et al., 2005). It is seen that aronia pulp has higher ME and NE_L values than grape pulp. The CH_4 content of the rations varied between 6.56-11.51 ml. The use of aronia pulp and wet brewers

grain together significantly decreased the CH_4 content of the ration. CO_2 and H_2 are released by the breakdown of nutrients in the rumen. Methanogenic archaea use H_2 as energy and provide CH_4 formation (Beauchemin et al., 2020). The addition of aronia pulp to the ration increased rumen degradation and reduced CH_4 production in the rumen due to the high level of antioxidants it contains. The high CP content of wet brewers grain caused an increase in the amount of CH_4 with proteolysis in the rumen. Ülger et al. (2020) found the CH_4 amounts of lemon, orange and mandarin pulp silages as 12.38, 11.73 and 11.77 ml, respectively. It is seen that aronia pulp has lower CH_4 amounts than lemon, orange and mandarin pulp silages. Aronia pulp contains high tannin content. Since condensed tannins can bind to carbohydrates and proteins (from feed and also from microbial enzymes), their degradation in the rumen is inhibited (McSweeney et al., 2001). Monomers formed with condensed tannins such as flavanols like gallocatechin and epigallocatechin galate can reduce gas production and IVOMD, while epicatechin and quarsetin did not affect these parameters (Sinz et al., 2018). Aronia pulp polyphenols are mainly composed of cyanidins and polymeric proanthocyanidins, condensed tannins and lower amounts of chlorogenic acids, quercetin and epicatechin (Määttä-Riihinen et al., 2004; Pieszka et al., 2015). Sinz et al. (2018) reported that inhibition of rumen fermentation by aronia pulp was more effective for condensed tannins than for monomeric epicatechin or quercetin. In a similar study, it was determined that liquorice leaves and pulp reduced CH_4 amounts (Abarghuei and Salem, 2021).

When the parameters related to the rumen fluid of the rations were evaluated, the pH value of the rumen fluid was measured as 7.20 at the beginning and changed between 6.82-7.15 at the 48th hour of incubation. When feeds are broken down in the rumen, volatile fatty acids (VFA) are released into the environment, these fatty acids decrease the pH level in the rumen fluid and increase the acidity of the environment (Erten et al., 2023b). In the study, aronia pulp improved the rumen pH value thanks to the polyphenol compounds it contains. At the beginning of the incubation, the number of protozoa in the rumen fluid was 0.63 x10^{5}, while the number of protozoa ranged between 0.94-1.25 x10^{5} at the 48th hour of incubation. It is seen as a result of the suppression of the development of lactic acid fermenting bacteria and protozoa in acidic environment and stimulation of the development of acid-resistant lactic acid producing bacteria (Öztürk and Pişkin, 2009). An excessive increase in lactic acid and VFA production reduces the number of protozoa (Gümüş, 2014). Although aronia pulp has rumen degradation and VFA production, it can be said that it has a positive effect on rumen protozoa numbers. At the beginning of the incubation, rumen fluid viscosity value was determined as 0.206 mm^{2}/s. At the 48th hour of incubation, this value was determined as 0.370-0.436 mm^{2}/s.

Rumen fluid viscosity, which is an indicator of nutrient breakdown, is an important value. With the increase in nutrient breakdown, the pH value of rumen fluid decreases and the number of protozoa decreases. In aronia pulp, viscosity value increased depending on the dose increase. However, the pH value of rumen fluid and the number of protozoa also increase accordingly. In this case, aronia pulp is a raw material with high digestibility and also has positive effects for rumen microflora. According to the data obtained from the research data, CH_4, and viscosity values increased with the increase in GP value, while pH and protozoa values decreased. When the feeds are broken down in the rumen, VFA is released into the environment, these fatty acids increase the acidity of the environment by decreasing the pH level in the rumen fluid (Erten et al., 2023b). Protozoa, which become sensitive at low pH levels, lose their lives with increasing acidity (Erten et al., 2024; Koç et al., 2024). Accordingly, pH value was positively correlated with protozoa value. CH_4 and CO_2 are formed by nutrient breakdown in rumen (Erten et al., 2023c). CH_4 and GP were positively correlated. Viscosity is characterised as the resistance to fluidity. Starch in the rumen decreases the viscosity of the rumen fluid with the breakdown in the rumen. This situation directly increases the viscosity. Viscosity value was found to be negatively correlated with protozoa value. The increase in fragmentation not only increases the viscosity but also decreases the rumen pH level. Thus, protozoa decrease because they become sensitive at low pH levels (Erten et al., 2023b).

CONCLUSION

The number of studies on the use of aronia pulp in animal nutrition is limited. In the research, it was determined that the addition of aronia pulp to the ration increased feed digestibility and made a positive contribution to the rumen microbiota. However, aronia pulp, which is considered as waste, needs to be increased especially *in vivo* studies for its widespread use in animal nutrition. As a result, the use of aronia pulp instead of wet brewers grain in ruminant rations can be recommended.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Original Article

Kuraklık Tehdidi Altında Türkiye Tarımı: Uzman Görüşleriyle Bir SWOT Analizi

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ÖZ

Bu çalışma, Türkiye tarım sektörünün stratejik bir durum analizini sunmaktadır. Bu amaçla, tarım sektörünün içsel güçlü ve zayıf yönleri ile dışsal fırsat ve tehditleri SWOT (Strengths, Weaknesses, Opportunities, Threats) analizi çerçevesinde değerlendirilmiştir. Akdeniz Havzası'nda iklim değişikliği kaynaklı kuraklık olaylarının şiddet ve sıklığındaki artış projeksiyonları dikkate alınarak sürdürülebilir uyum ve azaltım stratejileri için politika önerileri geliştirilmesi hedeflenmiştir. Bu kapsamda, ilgili konunun uzmanı akademisyenler ve en az beş yıllık çalışma deneyimi olan tarımsal saha profesyonellerinden oluşan 15 kişiyle derinlemesine görüşmeler gerçekleştirilmiştir. Yarı yapılandırılmış görüşme formuyla toplanan veriler, MAXQDA 2024 nitel analiz programına aktarılmış ve tematik analize tabi tutulmuştur.

Çalışmanın bulgularına göre, iklim çeşitliliği, coğrafi konum, doğal kaynaklar ve biyolojik çeşitlilik Türkiye tarım sektörünün güçlü yönlerini teşkil etmektedir. Ek olarak, zengin tarımsal miras, alternatif üretim teknikleri ve genç nüfus potansiyeli önemli fırsatlar sunmaktadır. Ancak, zayıf kurumsal yapı, teknoloji ve altyapı eksiklikleri, kısa vadeli istikrarsız politikalar, bilinçsiz kaynak kullanımı, üretici eğitimindeki yetersizlikler sektör için önemli zayıflıklar olarak belirlenmiştir. Öte yandan, küresel ısınma ve iklim değişikliği başta olmak üzere çevresel ve iklimsel tehditler, göç olgusu, gıda güvencesizliği, yüksek ithalat bağımlılığı tarımsal üretimin geleceğini ve sürdürebilirliğini ciddi şekilde tehdit etmektedir. Sonuç olarak, Türkiye tarım sektörünün sürdürülebilir geleceği; iklim çeşitliliği ve genç nüfus potansiyeli gibi avantajların korunup geliştirilmesine, altyapı ve eğitim eksikliklerinin giderilmesine, ithalat bağımlılığı, kuraklık ve diğer iklimsel tehditlere karşı stratejik direnç geliştirilmesine bağlıdır.

Anahtar kelimeler: Tarım sektörü, kuraklık, güçlü yönler, zayıf yönler, fırsatlar, tehditler.

Agriculture in Türkiye Under Drought Threat: A SWOT Analysis Based on Expert Views

ABSTRACT

This study presents a strategic situation analysis of the Turkish agricultural sector. For this purpose, the sector's internal strengths and weaknesses, along with external opportunities and threats, were assessed within the framework of a SWOT analysis. The study aimed to develop policy recommendations for sustainable adaptation and mitigation strategies, considering the projected increase in the severity and frequency of climate change-induced drought events in the Mediterranean Basin. To achieve this, in-depth interviews were conducted with 15 participants, comprising expert academics in relevant fields and agricultural field professionals with at least five years of experience. Data collected through a semi-structured interview form were transferred to MAXQDA 2024 qualitative analysis software and subjected to thematic analysis.

The study's findings indicate that climatic diversity, geographical location, natural resources, and biodiversity constitute the core strengths of the Turkish agricultural sector. Additionally, a rich agricultural heritage, alternative production techniques, and youth demographic potential offer significant opportunities. However, a weak institutional structure, technological and infrastructural deficiencies, short-term unstable policies, unconscious resource use, and inadequacies in producer education were identified as significant

weaknesses for the sector. Furthermore, environmental and climatic threats, particularly global warming and climate change, along with migration, food insecurity, and high import dependency, severely threaten the future and sustainability of agricultural production. In conclusion, the sustainable future of the Turkish agricultural sector hinges on preserving and developing advantages such as climatic diversity and youth demographic potential, addressing infrastructural and educational shortcomings, and building strategic resilience against import dependency, drought, and other climatic threats.

Key words: Agriculture sector, drought, strengths, weaknesses, opportunities, threats.

GİRİŞ

Tarım, insanlık tarihinin en eski ve stratejik sektörlerinden biridir. Neolitik çağın başlarından itibaren dünyanın farklı ve nispeten küçük bölgelerinde toprağın işlenmesi ve bazı bitki ve hayvan türlerinin evcilleştirilmesiyle başlayan tarımsal pratikler (Mazoyer ve Roudart, 2006), Sanayi Devrimi'yle birlikte tarımsal mekanizasyon ve bilimsel ilerlemeler sayesinde verimlilikte büyük sıçramalar katetmiştir (Ali ve ark. 2024). 1960'lar ve 1970'lerde gelişmekte olan ülkelerin kalkınma politikalarının merkezinde yer alan bir sektörken, 1980'lerden itibaren neoliberal politikaların etkisiyle tarım, küresel kalkınma gündeminde geri planda kalmış (Dethier ve Effenberger, 2011), sermayenin merkezileşmesi ve çevresel duyarsızlık sonucu gelişen birtakım sorunlarla yüzleşmek zorunda kalmıştır (Güney, 2024). Türkiye özelinde benzer bir süreç yaşanmış, tarımsal destek mekanizmalarının daraltılması, tarım ürünleri fiyatlarında baskılanma ve iç ticaret hadlerinin sektör aleyhine belirgin şekilde bozulması gibi olumsuz sonuçlar gelişmiştir (Us ve Akbıyık, 2023).

1980'lerden 2000'li yılların başlarına uzanan dönemde, gelişmekte olan ülkelerde tarımsal destek ve teşvik sitemlerinin payı önemli ölçüde azaltılmış, sektörün kilit kurumları özelleştirilmiş ve bunun sonucunda tarım sektörü göz ardı edilen bir konuma gelmiştir (De Janvry, 2010). Bununla birlikte, sektörün aynı zamanda artan nüfus baskısı ve yoksulluk, iklim değişikliği, su kıtlığı ve doğal kaynakların tükenişi gibi çok boyutlu tehditlerle karşı karşıya kalması (Cengiz ve İlhan, 2008), uluslararası gündemi harekete geçirmiştir. Bu bağlamda yayımlanan iki rapor, tarım sektörünün stratejik önemine ilişkin farkındalığın yeniden canlanmasına yol açarak, tarım sektörünün kaybettiği saygınlığı yeniden tesis etmesinde ve kalkınma gündemlerinde merkezi bir konum edinmesinde belirleyici olmuştur (Dethier ve Effenberger, 2011). Bu raporlardan ilki, 2008 tarihli *Kalkınma için Tarım* başlıklı çalışmadır; açlık ve yoksullukla mücadeledeki kritik rolünün yanı sıra, tarımın diğer sürdürülebilir küresel hedeflere ulaşmadaki temel işlevinin anlaşılmasına önemli katkıda bulunmuştur (Byerlee ve ark, 2008). İkincisi ise 2009 yılında yayımlanan *Tarım Tol Ayrımında* olup, tarımın yalnızca gıda güvenliği ve yoksulluk azaltmadaki merkezi konumunu değil, aynı zamanda çevresel bozulmanın önlenmesi ve sosyal adaletsizliklerle mücadeledeki vazgeçilmez rolünü de sistematik biçimde vurgulamıştır (IAASTD, 2009). Söz konusu raporların etkisiyle literatürde, gıda egemenliği, gıda güvencesizliği ve küresel gıda krizleri gibi kavramsal çerçeveler ekseninde tarım sektörünün mevcut durumu ve gelecek perspektifleri yoğun şekilde tartışılmaya başlanmıştır.

Küresel iklim değişikliği, yerkürenin hidrolojik döngüsünde ciddi bozulmalara yol açarak kuraklık olaylarında belirgin bir artışa neden olmaktadır. Hükümetlerarası İklim Değişikliği Paneli (IPCC)'ye göre, bu değişimler sonucunda kuraklıkların; sıklığında önemli artışlar, şiddetinde gözle görülür yükselişler, coğrafi dağılımında genişleme eğilimleri gözlemlenmektedir (IPCC, 2014; 2022). Bu durum, doğrudan su kaynaklarını, gıda üretim zincirlerini ve tarımsal faaliyetleri küresel ölçekte tehdit etmektedir. İklim modellerinin projeksiyonları, bu olumsuz etkilerin önümüzdeki dönemlerde de devam edeceğini açıkça göstermektedir. Ancak etkilenme düzeyleri ülkeden ülkeye önemli farklılıklar gösterecektir. Özellikle, coğrafi konumları dezavantajlı olan, ekonomik kaynakları sınırlı bulunan ve iklim değişikliğine uyum kapasiteleri düşük olan gelişmekte olan ülkeler, bu süreçten en fazla etkilenecek gruplar arasında yer almaktadır (Tumwine ve ark., 2019).

Tarım sektörü büyük ölçekte suya bağımlıdır. Küresel ölçekte kullanılan suyun %69'u tarımsal, %19'u endüstriyel ve %11'i içme/kullanma amaçlıdır (FAO Aquastat, 2016). Türkiye küresel kullanımla paralel olarak suyun en fazla kullanıldığı sektör tarımdır. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı (ÇŞB) istatistiklerine göre kaynaklardan çekilen suyun %77'si tarım, %23'ü ise içme, kullanma ve sanayi amaçlı harcanmaktadır (ÇŞB, 2022). İklim değişikliği kaynaklı yüksek sıcaklıkların, yoğun buharlaşmanın, uzun süreli kuraklıkların küresel ölçekte su döngüsünde önemli değişiklikler yapması ve su kaynakları üzerinde ciddi baskılar oluşturması öngörülmektedir. Bu bağlamda her derecedeki iklim değişimi bile tarım üretimini ve bağlantılı süreçleri önemli ölçüde etkileme potansiyeli nedeniyle, tarım sektörü iklim değişikliğinden en fazla etkilenmesi beklenen alanlardan biridir (Tao ve ark., 2011).

Cumhuriyetin ilk yıllarından günümüze kadar geçen sürede Türkiye'de önemli kuraklık hadiseleri yaşanmıştır. Kuraklık olayları, toplum üzerinde sosyal ve ekonomik yönden ciddi etkiler bırakmış ve çevre üzerinde önemli tahribatlar yaratmıştır. 1925-1929 yılları arasında Anadolu topraklarını geniş bir kısmında etkili

olan kuraklıkta çiftçiler, 1929 buhranın da etkisiyle derinleşen ekonomik koşullarda anormal borçlanmalar ve toprak kaybıyla sonuçlan bir süreç yaşamıştır (İnci, 2010). 1960'lı yıllarda Anadolu'nun birçok ilini etkileyen kuraklık ise kırsal alanlarda kıtlığa varan ve kente göçü hızlandıran bir dizi sosyoekonomik sonuçlar doğurmuştur (Gökgöz, 2019). Daha yakın tarihler olarak, 2007 ve 2019-2020 yıllarında meydana gelen kuraklık olaylarında, tarımsal üretimde önemli kayıplara ve kentsel su kaynaklarının kritik eşiklere düşmesine neden olmuştur. Bu dönemde Türkiye'nin bütün bölgelerinde yağışlar %10,8-%29 civarında daha az gerçekleşmiştir. (Kapluhan, 2013; Türkeş, 202; TZOB, 2011; Yıldız, 2021). Ayrıca, İstanbul ve İzmir gibi yoğun nüfuslu şehirlerin içme/kullanma suyunun kritik seviyelere düşmesi önemli bir gündem olarak tartışılmış ve gelecekte yaşanacak olası kuraklıklarda su kıtlığının toplumsal ve ekonomik etkilerinin derinleşeceğine dikkat çekilmiştir.

Türkiye'de neoliberal politikaların devreye alındığı yıl başlangıç olarak ele alındığında tarım sektörünün Gayri Safi Yurt İçi Hasıla (GSYİH) katkısının oransal olarak düzenli bir düşüş eğiliminde olduğu gözlemlenmektedir. 1980 yılında Türkiye'de tarımsal üretimin GSYİH içindeki payı %24 iken (Lise, 2006), Türkiye İstatistik Kurumu (TÜİK) verilerine göre bu oran 2000 yılında %10'a, 2023 yılında ise %6,2'ye kadar gerilemiştir (TÜİK, 2024b). Tarım sektöründeki bu ekonomik daralma, aynı zamanda kuraklık gibi dış etkenlere karşı sektörü daha kırılgan hale getirmektedir. Türkiye'de istihdam edilen 31 milyon 632 bin kişiden 4 milyon 695 bini tarım sektöründe yer almakta olup, istihdam edilen her altı kişiden biri tarım sektörüne bağımlıdır (TÜİK, 2024a). Bu durum, tarımsal üretimde yaşanacak olumsuzlukların hem kırsal kalkınma hem de gıda güvencesi açısından önemli olumsuz sonuçlar doğurabileceğine işaret etmektedir.

Akdeniz havzasında kuraklık olaylarının gelecekte daha sık ve şiddetli hale geleceği öngörülmektedir. Bu bağlamda Türkiye, iklim değişikliğinin olası etkileri açısından yüksek risk taşıyan ülkeler arasında değerlendirilmektedir (IPCC, 2022). Akdeniz havzasında tarımsal ve ekolojik kuraklıkların artış eğiliminde olması (IPCC, 2023), büyük ölçüde tarım sektörüne bağımlı kırsal nüfusun geleceğini tehdit etmektedir. Halihazırda günümüz iklim şartlarına göre Türkiye arazisinin yaklaşık %60'ında çeşitli derecelerde kurak iklim koşulları hakimdir (Türkeş, 2021). Kuraklık süreçlerinde bu alanlarda yapılan tarımsal sulama, kuraklık riskini ve iklim etkilerini azaltmada etkili olup çeşitli geçim faydaları sağlayabilmektedir. Ancak, su kaynaklarının hızla tükenmesi ile toprak tuzluluğunun artması gibi olası olumsuz çıktılar, tarımsal sürdürebilirliği zorlaştırabilmekte ve ekolojik dengeyi tehdit edebilmektedir (IPCC, 2023).

Nihai tahlilde Türkiye'de tarım sektörünün her ne kadar GSYİH'ye katkısı oransal olarak düşük görünse de ülke ekonomisine katkısı ve istihdamdaki yeri son derece önemlidir. Ayrıca iklim krizi, gıda güvencesizliği ve gıda egemenliği tehditlerinin sıkça tartışıldığı bir gelecekte, kendine yetebilen bir tarım sistemine sahip olmak bir ülke için stratejik bir gerekliliktir. Bu stratejik önem, özellikle iklim kaynaklı riskler karşısında savunmasızlıkla doğrudan ilişkilidir. Nitekim kuraklık riskinin boyutları, aşağıdaki denklemle formüle edilebilir:

Kuraklık Riski = (Kuraklık Olasılığı) × (Maruz Kalınan Nüfus ve Varlıklar) × (Zarar Görebilirlik)

Yukarıda verilen denklemde formülize edildiği gibi; bir ülkenin kuraklık riski, kuraklık olaylarının olasılığı, nüfus/varlıkların maruziyet derecesi ve zarar görebilirlik bileşenleriyle doğrudan ilişkilidir. IPCC projeksiyonları, Türkiye'de kuraklık sıklığının artacağını ortaya koymaktadır. Kuraklık olasılığını ortadan kaldırmak mümkün olmasa da maruziyet ve zarar görebilirlik gibi yönetilebilir bileşenler sektörel riskin azaltılmasında kritik rol oynar. Bu bağlamda sektörün başa çıkma kapasitesi ile mücadele yeteneğinin stratejik değerlendirilmesi önem kazanmaktadır. Çalışmanın amacı da Türkiye tarım sektörünün kuraklık bağlamındaki tehdit/fırsat dinamiklerini ve içsel güçlü/zayıf yönlerini sistematik biçimde analiz ederek stratejik bir yol haritası oluşturmaktır. Bu amaçla içsel-dışsal bütünleşik değerlendiren stratejik bir çerçeve olan SWOT (Strengths, Weaknesses, Opportunities, Threats) analizi benimsenmiştir. Nitel-nicel veri uyumluluğu ve analitik esnekliği sayesinde SWOT analizi; kamu politikalarından sektörel ölçekli değerlendirmelere kadar geniş uygulama yelpazesine sahiptir (Benzaghta ve ark., 2021; Helms ve Nixon, 2010). SWOT metodolojisi, tarım sektöründe durum analizi (Akhtar ve Pirzada, 2014), ulusal strateji değerlendirmeleri (Gc ve Ghimire, 2018), bölgesel analizler gerçekleştirme (Çetin ve Canan, 2024), dijital dönüşüm uygulamalarının etki değerlendirmesi gibi çok katmanlı bağlamlarda yaygın ve başarılı bir şekilde uygulanmaktadır.

Bu çalışma, Türkiye tarım sektörünün içsel/dışsal faktörlerini uzman görüşleri yoluyla değerlendirerek; güçlü yönlerin fırsatlarla sinerjik etkileşimini, zayıf yönlerin sektörel ilerlemeyi kısıtlayıcı potansiyelini ve tehditlerin kümülatif riskini ortaya koymayı hedeflemektedir. Özellikle kuraklık riski bağlamında uzman görüşleriyle desteklenen sektörel SWOT analizi yapan bir çalışma olması nedeniyle literatürdeki teorik ve metodolojik boşluğu doldurma potansiyeli taşımaktadır. Elde edilen bulgular politika yapıcıların ve sektör aktörlerinin karar alma süreçlerine katkı sunmasının yanı sıra tarım ekonomisi ve risk yönetimi literatürüne özgün bir katkı sağlamaktadır.

MATERYAL VE METOT

Gelecekte olası kuraklık durumları karşısında Türkiye tarım sektörünün güçlü ve zayıf yönlerinin, aynı zamanda fırsatlarının ve tehditlerinin belirlenmeye çalışıldığı bu çalışmada nitel araştırma yaklaşımı temel alınmıştır. Nitel çalışmalar, "gözlem, görüşme ve doküman analizi gibi nitel veri toplama tekniklerinin kullanıldığı, algıların ve olayların doğal ortamda gerçekçi ve bütüncül bir biçimde ortaya konmasına yönelik nitel bir sürecin izlendiği araştırma" olarak tanımlanabilir (Yıldırım ve Şimşek, 2008).

Görüşme, nitel çalışmalarda başvurulan veri toplama tekniklerinden biridir. Görüşmeler yüz yüze, telefonla arama veya çevirim içi platformlar yoluyla yapılabilmektedir. Bu çalışmada zaman, maliyet ve katılımcıların uygunluğu göz önünde bulundurulmuş ve görüşmeler uzaktan erişim üzerinden çevirim içi olarak yapılmış ve kayıt altına alınmıştır. Katılımcılardan kayıt öncesinde sözlü onay alınmış ve etik kurul protokollerine uyulmuştur.

Araştırmanın problemine ilişkin olarak SWOT Analizi yapılması planlanmıştır. Araştırma probleminin derinlemesine analizi için SWOT başlıkları yol gösterici olmuştur. Yeteri doygunluğa erişene dek veri toplamak ve derinlemesine gözlem elde etmek istenmiştir.

Araştırmanın katılımcıları, amaçlı örnekleme yöntemiyle belirlenmiş olup kuraklık ve tarım sektörü alanlarında uzmanlığa sahip bireylerden oluşmaktadır. Katılımcı grubu; iklim değişikliği, göç, kuraklık ve tarım politikaları konularında akademik yayınları bulunan araştırmacılar ile sahada en az beş yıl deneyimi olan sektör profesyonellerini kapsamaktadır. Akademisyenlerin seçiminde, ilgili alandaki bilimsel üretkenlik dikkate alınmış, literatür taraması sonucunda belirlenen isimlere ulaşılarak gönüllülük esasına dayalı katılım sağlayanlarla derinlemesine görüşmeler yürütülmüştür. Saha çalışanlarında ise asgari beş yıllık sektörel deneyim ön koşul olarak benimsenmiştir.

Çalışma 15 katılımcı ile gerçekleştirilmiş ve katılımcılar "K-01, K-02, … K-15" şeklinde kodlanmıştır. Katılımcıların 12'si erkek, 3'ü kadındır. Katılımcılarından en genç olanı 31 yaşında iken en yaşlı olanı ise 75 yaşındadır. Yıl bazında K-02, 6 yıl ile en az deneyimli; K-05, 50 yıl ile en çok deneyime sahip katılımcıdır. Çalışmaya tarımsal sulama, bitki koruma, bitki besleme, tarım ekonomisi, toprak bilimi, beşerî coğrafya gibi çeşitli alanlardan akademisyenler ve saha çalışanları katılım sağlamıştır (Çizelge 1). Farklı çalışma alanlarından katılımcıların olması araştırılan konunun geniş bir perspektiften ele alınmasını sağlamıştır. Ayrıca, çalışma bulgularının tarım sektörü için daha kapsamlı ve geçerli olmasına katkı sağlanmıştır. Amaçlı-maksimum çeşitlilik örnekleme olarak da ifade edilen bu yaklaşım, araştırılan durum veya olgunun derinlemesine incelenmesine olanak sağlaması yönüyle nitel araştırma yaklaşımına uyumludur (Büyüköztürk ve ark., 2019).

Çizelge 1. Katılımcı Bilgileri

	Cinsiyet	Yaş	Çalışma/Uzmanlık Alanı	Deneyim (Yıl)	Şehir	Kurum/Mesleki Rol
K-01	Erkek	31	Tarımsal Sulama	8	Bitlis	TOB*/Saha Çalışanı
K-02	Erkek	32	Bitki Koruma	6	Muş	TOB/Saha Çalışanı
K-03	Erkek	33	Bitki Besleme ve Koruma	9	Şanlıurfa	ÖS**/ Saha Çalışanı
K-04	Erkek	49	Tarımsal Makine ve Teknoloji	29	Muş	TOB/ Saha Çalışanı
K-05	Erkek	75	Tarım Politikaları	50	İzmir	Bağımsız/Akademisyen
K-06	Erkek	64	Toprak Bilimi	40	Adana	Üniversite/Akademisyen
K-07	Erkek	57	Tarım ve İktisat Politikaları	33	İzmir	Üniversite/Akademisyen
K-08	Kadın	38	Bahçe Bitkileri ve Seracılık	13	İzmir	TOB/Saha Çalışanı
K-09	Erkek	24	Beşerî Coğrafya- Göç	6	Van	Üniversite/Akademisyen
K-10	Erkek	65	Toprak Bilimi ve Bitki Besleme	44	Manisa	BŞB***/Akademisyen
K-11	Erkek	45	Kırsal Kalkınma	16	İzmir	Üniversite/Akademisyen
K-12	Erkek	37	Tarım Ekonomisi	11	İzmir	Üniversite/Akademisyen
K-13	Kadın	47	Bitki Besleme ve Toprak Bilimi	26	İzmir	Üniversite/Akademisyen
K-14	Erkek	48	Organik Tarım	11	Diyarbakır	Bağımsız/Saha Çalışanı
K-15	Kadın	57	Tarım Ekonomisi	24	İzmir	TOB/Saha Çalışanı

*Tarım ve Orman Bakanlığı, ** Özel Sektör, ***Büyükşehir Belediyesi

Çalışmada aşağıdaki sorulara cevap aranmıştır;

- Olası kuraklık olaylarında Türkiye tarım sektörünün güçlü yönleri nelerdir?
- Olası kuraklık olaylarında Türkiye tarım sektörünün zayıf yönleri nelerdir?

- Olası kuraklık olaylarında Türkiye tarım sektörünün fırsatları nelerdir?
- Olası kuraklık olaylarında Türkiye tarım sektörünün tehditleri nelerdir?

Görüşmelerden elde edilen veriler deşifre edildikten sonra MAXQDA 2024 nitel veri analiz programına aktarılmış ve analizlere başlanmıştır. Nitel olarak toplanan verilerin kodlara, alt temalara ve temalara dönüştürülme sürecine 'açık kodlama' denmektedir (Bulduklu, 2019). Bu bağlamda çalışmanın kodlama süreci açık kodlama ile uyumludur. Birinci döngü kodlama yöntemi bitirildikten sonra oluşturulan kodlar gözden geçirilmiş ve ikincil döngü kodlamada kategoriler, alt temalar ve temalar altında şekillendirilmiştir. Ayrıca SWOT analizi kapsamında önceden tasarlanmış soruların ve belirlenmiş tematik çerçevenin varlığı, araştırmada tümdengelimsel tema analiz metodunun benimsenmesini zorunlu kılmıştır.

BULGULAR VE TARTIŞMA

Bu başlık altında temalara ve alt temalara dair genel bilgilerin yer aldığı beş başlığa yer verilmiştir. Alt tema analizinde, en çok tekrarlanan alt temadan en az tekrarlanan alt temaya doğru bir sıralama benimsenmiştir.

Tema ve Alt Temalara Dair Genel Bilgiler

Çalışmada uzman görüşmeleri yoluyla Türkiye tarım sektörünün olası kuraklık durumlarındaki güçlü ve zayıf yanları ile tehditleri ve fırsatlarına yönelik bir analiz yapılmıştır. Elde edilen verilerden kodlar oluşturulmuştur. İkincil döngü kodlamadan sonra kodlardan kategoriler ve alt temalar oluşturulmuştur. Daha sonra oluşturulan kategori ve alt temalar *Türkiye Tarımının Güçlü Yönleri, Türkiye Tarımının Zayıf Yönleri, Türkiye Tarımının Fırsatları* ve *Türkiye Tarımının Tehditleri* olmak üzere dört tema altında birleştirilmiştir (Çizelge 2). Belge başına her kategorinin bir kere değerlendirildiği çalışma bulgularına göre tarım sektörü için güçlü yönleri temsil eden kategorilerin frekans değeri 41, zayıf yönleri temsil eden kategorileri frekans değeri 41, fırsatları temsil eden kategorilerin frekans değeri 25, tehditleri temsile eden kategorilerin frekans değeri ise 53'tür.

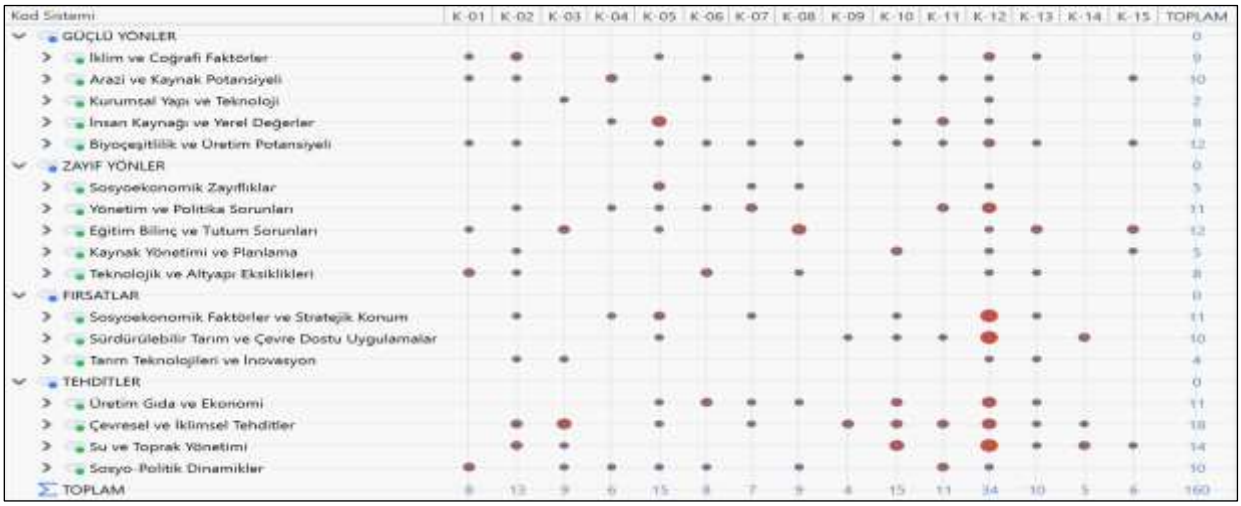
Katılımcılara olası kuraklık durumlarında tarım sektörünün güçlü yönleri sorulmuştur. Araştırma bulgularına göre katılımcılar; biyoçeşitlilik ve üretim potansiyeli, arazi ve kaynak potansiyeli, iklim ve coğrafi faktörler, insan kaynağı ve yerel değerlerin tarım sektörünün güçlü yönleri olduğunu yoğun olarak ifade etmiştir. Kurumsal yapı ve teknolojiden iki kez güçlü yön olarak bahsedilmiştir.

Katılımcılara olası kuraklık durumlarında tarım sektörünün zayıf yönleri sorulmuştur. Bulgulara göre katılımcılar; eğitim bilinç ve tutum sorunları, yönetim ve politika sorunları, teknoloji ve alt yapı eksikleri tarım sektörünün zayıf yönler olarak bildirmiştir. Kaynak yönetimi ve planlama ile sosyoekonomik zayıflıklar ise sektörün zayıf yönleri olduğu konusunda beşer kez dile getirilmiştir.

Katılımcılara tarım sektörünün fırsatları sorulmuştur. Araştırma bulgularına göre katılımcılar; stratejik konum ve sosyoekonomik faktörleri, sürdürülebilir tarım ve çevre dostu uygulamaları ile tarım teknolojileri ve inovasyonu tarım sektörü için fırsat olarak değerlendirmiştir.

Katılımcılara tarım sektörünü bekleyen tehditler sorulmuştur. Bulgulara göre katılımcılar; çevresel ve iklimsel tehditleri, su ve toprak yönetimini, üretim gıda ve ekonomiyi ile bazı sosyopolitik dinamikleri tarım sektörü için gelecekte tehdit olarak ele aldıklarını belirtmiştir

Çizelge 2. Tema ve Alt Temaların Yoğunluk Değerleri



Kod Sistemi	K-01	K-02	K-03	K-04	K-05	K-06	K-07	K-08	K-09	K-10	K-11	K-12	K-13	K-14	K-15	TOPLAM
GÜÇLÜ YÖNLER																0
İklim ve Coğrafi Faktörler	•	•			•			•		•		•	•			9
Arazi ve Kaynak Potansiyeli	•	•		•		•			•	•	•	•			•	10
Kurumsal Yapı ve Teknoloji			•									•				2
İnsan Kaynağı ve Yerel Değerler				•	•					•	•	•				8
Biyoçeşitlilik ve Üretim Potansiyeli	•	•			•	•	•	•		•	•	•	•		•	12
ZAYIF YÖNLER																0
Sosyoekonomik Zayıflıklar					•		•	•				•				5
Yönetim ve Politika Sorunları		•		•	•	•	•				•	•				11
Eğitim Bilinç ve Tutum Sorunları	•		•		•			•				•	•		•	12
Kaynak Yönetimi ve Planlama		•								•		•			•	5
Teknolojik ve Altyapı Eksiklikleri	•	•				•		•				•	•			8
FIRSATLAR																0
Sosyoekonomik Faktörler ve Stratejik Konum		•		•	•		•			•		•	•			11
Sürdürülebilir Tarım ve Çevre Dostu Uygulamalar					•				•	•	•	•		•		10
Tarım Teknolojileri ve İnovasyon		•	•									•	•			4
TEHDİTLER																0
Üretim Gıda ve Ekonomi					•	•	•	•		•		•	•			11
Çevresel ve İklimsel Tehditler		•	•		•		•		•	•	•	•	•	•		13
Su ve Toprak Yönetimi		•	•							•		•	•	•	•	14
Sosyo-Politik Dinamikler	•		•	•	•	•		•			•	•				10
TOPLAM	6	13	9	6	15	8	7	9	4	15	11	34	10	5	6	160

Tema 1: Türkiye Tarımının Güçlü Yönleri

Şekil 1'de Türkiye tarımının güçlü yönlerini temsil eden alt temalar ve kategoriler gösterilmektedir. Buna göre, biyoçeşitlilik ve üretim potansiyeli konusu bağlamında ürün deseni esnekliği, zengin bitki ve biyoçeşitlilik, iklim uyumlu bitki varlığı gibi faktörler katılımcılar tarafından en yoğun dile getirilen güçlü yönler olmuştur. İklim ve coğrafi faktörler alt temasının altında değerlendirilen iklim çeşitliliği, mevsim çeşitliliği ve coğrafi konum gibi faktörler katılımcılar tarafından Türkiye tarım sektörü için güçlü yönler olarak belirtilmiştir. Bu konuda bazı katılımcıların ifadeleri şöyledir:

K-08: "Olası kuraklıklar için güçlü yanlarımız, Türkiye coğrafi konumu olarak hani Doğu Anadolu, İç Anadolu, Ege, Marmara her bölgede ürün desenimiz farklı, tek bir ürün desenimiz yok. Belki kuraklıkla dönemsel her bölgede daha farklı çalışmalar yaparak mücadele edebiliriz ülke genelinde. Şimdi bir meyvenin suya olan ihtiyacı ile bir zeytinin suya olan ihtiyacı bir tarla bitkisinin suya olan ihtiyacı farklı miktardadır."

K-02: "Yani tarım sektörü için Türkiye dediğim gibi jeopolitik olarak çok uygun bir ülke. Yani çünkü sürekli tekrarlanan o dört mevsim olayı aslında tarım sektörü için çok çok önemli bir durum. E çoğu ürün yetiştirilebiliyor. Bazı bölgelerimizde biliyorsun senede aynı tarladan üç defa ürün alınabiliyor. Farklı farklı ürünler aynı zamanda. İşte yazın farklı, kışın farklı, ilkbaharda farklı olmak üzere bu şekilde farklı farklı şeyler alınabilir. Türkiye bu açıdan oldukça makul bir yerde. Güçlü yanlar bunlar."

Türkiye, Avrupa'nın dokuz biyocoğrafik bölgesinden üçüne (Akdeniz, Karadeniz, İran-Anadolu) ev sahipliği yapmakta olup her biri farklı ekosistem özellikleri sergilemektedir. Bu coğrafi konfigürasyonun bir sonucu olarak; orman, dağ, bozkır, sulak alan, kıyı ve deniz ekosistemlerinin farklı kombinasyonlarıyla kıtasal ölçekte biyolojik çeşitlilik sergileyen bir mozaik yapı oluşturur. Ülkenin yedi fizyo-coğrafi bölgesinin kendine özgü iklim rejimleri ve ekolojik dinamikleri, bu benzersiz biyolojik zenginliğin temel belirleyicisidir (Birben ve Gençay, 2019; Muminjanov ve Karagöz 2019). Coğrafi özellikleri ve ekolojik koşulları çeşitli tarımsal ürünün yetiştirilmesine olanak sağlamaktadır (Atış ve ark. 2024). Örneğin; fındık, kiraz, incir, ayva gibi bazı tarımsal ürünlerin üretiminde dünyada ilk sırada yer almaktadır. Kavun, karpuz, şeftali, nektarin, badem ceviz, çilek, elma, kestane zeytin, antepfıstığı gibi ürünlerin üretiminde dünyada ilk sıralarda bulunmaktadır. (Karadeniz, 2022). Bu bağlamda iklim, coğrafya ve biyoçeşitlilik potansiyeli Türkiye tarımını güçlü kılan önemli etmenlerdir. Bunlarla beraber literatürde, denize kıyısı olan ülkelerin tarım ticaretinde çeşitli avantajlara sahip olduğu ve bu durumun kritik bir unsur olarak değerlendirildiği görülmektedir. Örneğin, Gc ve Ghimire (2018), tamamen kara sınırlarıyla çevrili olmanın, komşu ülkelerin tarım politikalarından etkilenme riskini arttırdığını ve bu durumun tarım sektörü için bir tehdit barındırdığını vurgulamaktadır. Bu bağlamda, Türkiye'nin birçok denize kıyısı olması tarım sektörünü güçlendirmektedir.

Arazi ve kaynak potansiyeli bağlamında su kaynaklarının varlığı, tarımsal alan yeterliliği ve çeşitliliği çeşitli ve verimli toprak yapısı, yıl boyu ekim potansiyeli katılımcıların tarafından güçlü yönler olarak belirtilmiştir. Katılımcılar bu konuda şöyle fikir belirtmiştir:

K-09: "Yani güçlü yanı için ne söyleyebilirim… İlk etapta aklıma gelebilen, belki bunun üstüne de çok detaylı düşünmek gerekebilir ama en azından hani doğu ve güneyde yer alan ülkelere göre su kaynakları açısından daha zengin. Türkiye su zengini bir ülke değil ama o ülkelerle kıyasladığımız zaman nispeten daha zengin."

K-11: "Ya güçlü yani bir kere evet yani dediğim gibi ülke olarak değerlendiriyorsak diğer ülkelerle başta yaptığım, karşılaştığımda burada güçlü bir yön yani hala daha kayıplarımıza rağmen ciddi bir tarımsal araziye sahibiz. Ve bu tarımsal arazi üzerinde birtakım uygulamaları, alışkanlıkları değiştirerek hala daha hem başta ülke nüfusu olmak üzere ciddi bir nüfusu besleyecek bir potansiyeli hala daha sahibiz. Bu en güçlü yönlerimizden birisi."

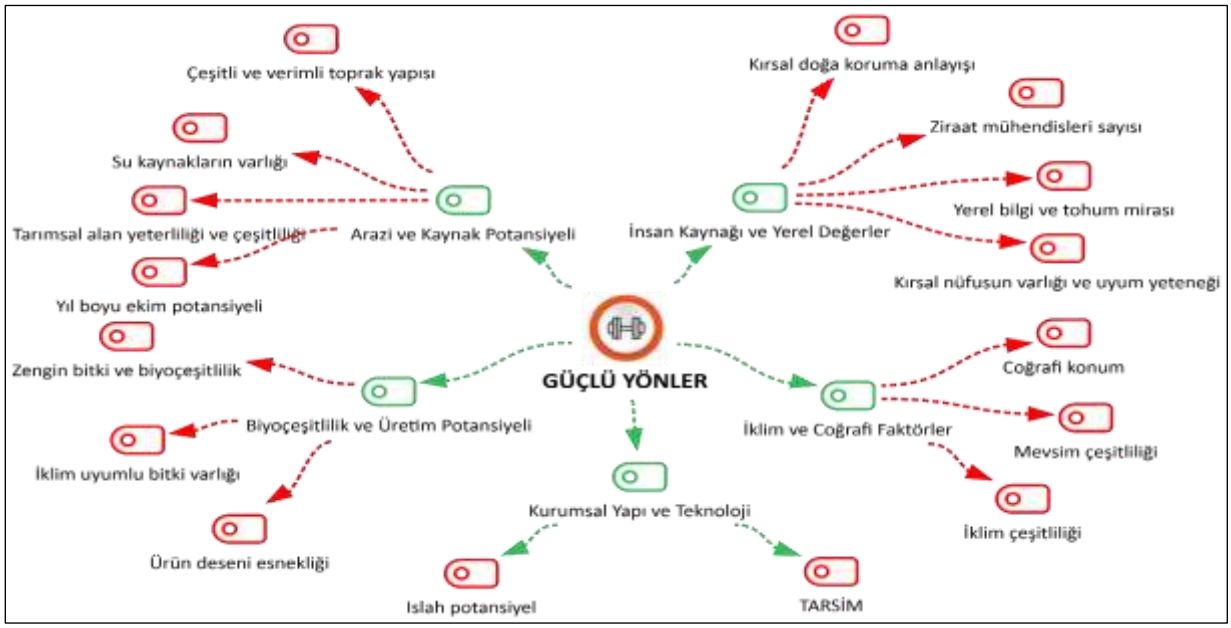
Tarım ve Orman Bakanlığı (TOB) verilerine göre Türkiye, yüzölçümünün yaklaşık üçte birine tekabül eden yaklaşık 24 milyon hektar ekilebilir tarım arazisine sahiptir (TOB, 2023). Çayır ve mera alanları eklendiğinde toplam tarımsal alan yaklaşık 38 milyon hektara ulaşmakta ve bu, ülke yüzölçümünün %50'sini aşmaktadır (ÇŞB, 2024). Akhtar ve Pirzada (2014)'ün vurguladığı üzere, geniş tarımsal arazilere sahip olmak güçlü bir tarım sektörü için temel unsurdur. Hem mutlak hem de göreceli büyüklük açısından bu veriler, Türkiye'nin sahip olduğu tarımsal potansiyeli somutlaştırmakta ve çalışma bulgularının geçerliliğini nicel verilerle pekiştirmektedir.

İnsan kaynağı ve yerel değerler bağlamında kırsal nüfusun varlığı ve uyum yeteneği, ziraat mühendislerini sayısı, kırsalın doğayı koruma anlayışı, yerel bilgi ve tohum mirası katılımcıların güçlü yanlar olarak atfettiği kategoriler olarak göze çarpmaktadır. Kurumsal yapı ve teknoloji konusunda katılımcılar ıslah potansiyelini ve Tarım Sigortaları Havuzu (TARSİM)'i güçlü yönler olarak değerlendirmektedir. K-11, K-05 ve K-03' ün bu konudaki ifadeleri şöyledir:

K-11. "Bir diğeri, bir diğeri bence dedim ya bu uygulamaları değiştirmek, alışkanlıkları değiştirmek. Bu her zaman zor olarak ifade edilir. Evet, tabii ki zorluğu vardır. Ancak özellikle kriz dönemlerinde çiftçilerin bu tür değişikliklere uyum kapasitesi artar. Çok üst düzeye çıkar. Bu anlamda Türkiye'deki çiftçiler farklı farklı bölgelerdeki çiftçiler bunun sınavını da tarihsel süreçte farklı farklı zamanlarda vermişlerdir. Yani üretim desenlerinin değişmesi

anlamında. En basit örneğini işte burada ben hani komşu Akhisar'dan vereyim. 2002 yılında çıkan tütün kanunu sonrası tütün üretimiyle anılan Akhisar bugün artık çok ciddi bir zeytin üreticisi kent haline gelmiştir."
K-05: "Türkiye'de bir köylü nüfusu var. Bunu bazıları zayıf yan olarak görebilirler ama ben güçlü yan olarak görüyorum. Çünkü köylüler daha böyle şeye eğilimli olabilirler yani doğayı korumaya, onu savunma yönünde olabilirler. Türkiye'de hala daha güçlü yanlar bazı yerel tohumlar elimizde var. Hala daha yerel bilgiler, çiftçilerin yerel bilgileri söz konusu."
K-03: "Tarımda hızlı bir dönüşüm sağlanmak istenirse ıslah çalışması yapabilecek bir potansiyele sahiptir. O açıdan potansiyel çok, yeter ki yapılmak istensin. Bizde enerjisi çok hep yanlış bir şekilde harcıyoruz. Ondan dolayı bizde gerçek anlamda ıslah çalışmaları yapılmak istense acayip derecede bir potansiyele sahip olduğunuzu düşünüyorum. Bunu hızlı bir şekilde yapmaya başlayabiliriz ve yaparız da yani…"

Ülke geliri için tarımın GSYİH içindeki payı her ne kadar düşük olsa da istihdamdaki payı son derece yüksektir. Türkiye'de istihdam edilen 31 milyon 632 bin kişiden 4 milyon 695 bini tarım sektöründe yer almaktadır. Bir başka deyişle istihdam edilen her altı kişiden en az bir kişi tarım sektöründe istihdam edilmiştir (TÜİK, 2024). Kırdan kente göçün uzun yıllardır devam ettiği bir süreçte tarımsal iş günün halen yüksek olması Türkiye tarımı için güçlü bir faktör olarak durmaktadır. Ayrıca, yaklaşık 40 civarında bir sayıya ulaşan ziraat fakülteleri senede 4-5 bin civarında mezun vermektedir. Ülkedeki mevcut ziraat mühendisi sayısının ise 120 bin kadar olduğu düşünülmektedir (Çevik 2022). Nitelikli insan sayısı sektörü güçlü kılan etmenlerdendir. 2006 yılında faaliyete geçen TARSİM, bitkisel ürün sigortası, köy bazlı kuraklık verim sigortası, sera sigortası, büyükbaş hayvan hayat sigortası, küçükbaş hayvan hayat sigortası, su ürünleri hayat sigortası, kümes hayvanları hayat sigortası, arıcılık sigortası gibi birçok konuda hizmet sağlamaktadır (Pehlivan ve Akpınar, 2022). Türkiye tarım sigortaları tarihine yeni bir soluk getirmesi, devlet desteği sağlaması, birçok sigorta çeşidini tek çatı altında birleştirmesi, kamu-özel sektör ve sivil toplum iş birliği temelli olması kurumun güçlü yanlarıdır. Ancak Çiftyıldız ve İsel (2020)'in bahsettiği rekabeti engellemesi, tahsilat sorunları, deneyimsiz personel, eksik saha araştırmaları kurumun birtakım sorunları olduğunu göstermektedir.



Şekil 1. Güçlü Yönler

Tema 2. Türkiye Tarımının Zayıf Yönleri

Şekil 2'de Türkiye tarımının zayıf yönlerini temsil eden alt temalar ve kategoriler gösterilmiştir. Buna göre, eğitim, bilinç ve tutum sorunları alt teması çiftçilerde bilgi ve eğitim eksikliği, çiftçilerin pasif tutumu (adaptasyon ve mücadele konusunda), teknoloji ve değişime uyum sorunu, ile geleneksel tutumlar kategorilerini temsil etmektedir. Kategoriler, katılımcılar tarafından sıkça ifade edilen tarım sektörünün zayıf durumlarını ifade etmektedir. Bazı katılımcılar bu durumları şöyle ifade etmektedir:
K-12: "Az evvel söylediğim bilinç ve eğitimde çok büyük problem var. Üretici ne olduğunu bilmiyor, kuraklık riskini bilmiyor, iklim değişikliğini ne yapacağını bilmiyor. Eğitim ve farkındalık çok önemli. Hatta bunu bir üst boyuta çekip üretici değil bütün kademelerde belki de ana okuldan bahsedip, başlatıp bunun önemini vurgulamak lazım."
K-08: Zayıf yönlerimiz teknolojiye açık olmamamız, değişime açık olmamamız. Üreticilerimizle biz bunları çok konuşuyoruz hani oturmuş kalıplarımız var ülke genelinde özellikle çiftçilerimize. Eğitim, zayıf yanlarımız tarım

işçilerimizin hani eğitim seviyelerinin yükseltilmesi. Gençlerin tarıma yönlendirilmesi. Yani genç çiftçilerle konuşmak bazı şeyleri anlatmak belki daha kolay olabilir ama şimdi anadan babadan görme atadan görme şekilde biz tarımda hala öyle ilerliyoruz. O yüzden bu sıkıntıları yaşıyoruz yani biz. Ben çok gözlemliyorum."

Çalışmada, çiftçilerin tarımsal bilgi eksikliği ve yeniliklere kapalı olması, sektörün önemli bir zayıf yönü olarak tespit edilmiştir. Bu durum, Bilgin ve Medeni'nin (2023) çalışmasında da vurgulanmakta; araştırmacılar, çiftçilerin bitkisel üretim ve hayvancılık konularında yetersiz bilgiye sahip olmalarını tarım sektöründe yaşanan temel sorunlarından biri olarak değerlendirmektedir. Nitekim, bir saha araştırmasına göre üreticilerin %74'ü önceden bildiği tanıdığı ürünü ekmeyi tercih etmektedir. Buna karşın az su isteyen kuraklığa toleranslı ürün olması üreticiler için %28 oranında tercih sebebidir (KKB, 2023). Bu bulgular, çiftçilerin iklim değişikliğine dirençli tarımsal uygulamalara kıyasla, yerleşik geleneksel üretim yöntemlerine belirgin bir eğilim gösterdiğine işaret etmektedir. Yerel ölçekli bir çalışmada üreticilerin yetersiz teknik bilgiye sahip olduğu ayrıca yeniliğe uyum bağlamında öncülük edecek çiftçi sayısının azlığından bir zayıflık olarak bahsedilmiştir (Acıbuca ve ark., 2022). Çiftçilerin, günümüz şartlarında uygun görülmeyen eski usul üretim uygulamalarında ısrarcı olması; yöntem, teknik ve teknolojik yeniliklere uyum sağlayamaması zarar görebilirliği arttırdığı düşünülmektedir.

Yönetim ve politika sorunları, katılımcıların tarafından zayıf yön olarak en sık bahsedilen konulardan biri olmuştur. Ekonomi ve tarım yönetimindeki başarısızlıklar, uzun vadeli planlama eksikliği, tarımsal politikalarda istikrarsızlık, yetersiz ve siyasileştirilebilen teşvik sistemi, bürokratik engeller ve evrak yükü ile kontrol ve denetim eksikliği tarım sektörünün zayıflığını göstermektedir. Ayrıca, Teknoloji ve altyapı eksiklikleri kapsamında katılımcılar, sulama sistemlerinde dışa bağımlılık ve alt yapı sorunları, teknolojik yetersizlik, tarımsal sanayi yetersizliği, tarımsal Ar-Ge eksikliğinden zayıf olarak bahsetmiştir. Bazı katılımcılar bu durumu şöyle ifade etmektedir:

K-05: "Zayıf yönleri Türkiye'nin maalesef ekonomi ekonomi çok kötü yönetiliyor Ondan sonra en son bu para politikasındaki kötüleşme Türkiye tarımını çok şiddetli vurdu Çünkü Türkiye tarımı maalesef çok dışa bağımlı bir tarım haline geldi. O yüzden ekonominin kötü yönetiliyor olması, tarım ekonomisinin kötü yönetiliyor olması zayıf yön. Ondan sonra çiftçilerin yoksul olması ve eğitimsiz olması da gene zayıf yönlerinden. Tarım Bakanlığının kötü yönetiliyor olması bilgiye ve kalifiye insana değer verilmemiş olması zayıf yönlerimizden."

K-12: "Tarımsal politikalar uzun vadeli yapılmıyor. Yapılmadığı için de kısa vadelerde iptal edilip yeniden yapılmaya çalışılıyor ama sürekli Amerika'yı keşfetmek üzere yola çıkar ve yarı yolda geri dönüp yine Amerika'yı keşfetmeye çıkarsak bir yere varamayız doğal olarak. Yani bizim o yolculuğa devam etmemiz lazım. Plana sadık kalmamız lazım. Uyum stratejileri geliştirmemiz gerekiyor. Buradaki en büyük eksikliğimiz o. Biz uyuma yönelik işleri başka şeylerle karıştırıyoruz. Yani kavram kargaşası yaşıyoruz. Bunu toparlamamız lazım."

Yönetim ve politika zayıflıklarını Yavuz ve Dilek (2019) yapısal değişikler ve yönetimsel anlayış çerçevesinde ele almıştır. Araştırmacılar, Türkiye tarımsal yönetimde Bakanlık dahil kurumların yapısı devamlı olarak değişebildiğini, sektör ile ilgili kanunlar, yönetmelikler ve teşkilat yapılanmalarında önemli değişikler meydana geldiğini ancak, söz konusu değişimlerin, merkeziyetçi ve katı bürokratik işleyişi dönüştüremediği, ayrıca yerel paydaşların katılımını sınırladığı için kurumların verimli çalışamadığını vurgulamaktadır. Karami ve Agahi (2017) çalışmalarında, yerel paydaşların politika geliştirme aşamalarında aktif katılımının tarımsal politikaların güçlendirilmesinde önemli bir etken olduğunu vurgulamaktadır. Gc ve Ghimire (2018) politikaların iklim kaygısı gözetilmeden oluşturulmasına dikkat çekmektedir. Onlara göre, iklim değişikliğinin tarımsal sistemler için küresel ölçekte bir tehdit olmasına rağmen, ulusal tarım planlamalarında yeterince ele alınmamaktadır. Bunların yanında usta-çırak ilişkisinin eskiye nazaran zayıflaması, bürokrasi fazlalığı, bütçe yatırım ve personel yetersizlikleri, Ar-Ge çalışmalarına ilgisizlik ile birtakım personel özlük hakları ilgili kurumları faaliyet raporlarında zayıflıklar olarak bahsedilmektedir (TOB, 2023). Düzenli aralıklarla yapılan bir saha araştırması ise çiftçilerin teknolojik araçları kullanım amaçlarını irdelemiştir. Bu göre, çiftçilerin teknoloji ve internet kullanımın artan bir eğilimdedir (KKB, 2023). Ancak ilgili çalışma incelendiğinde söz konusu artışın hava durumunu takip, ürün fiyat bilgisi kontrolü, tarımsal destekler ve haberleri takip gibi uygulamalar ile sınırlı kaldığı görülmektedir. Oysaki, güçlü tarım ülkelerinde akıllı tarım uygulamaları olarak ifade edilen uydu, sensör teknolojileri, otomasyon sistemleri, uzaktan algılama gibi yeni nesil yüksek teknolojiler kullanılmaktadır. Bu uygulamalar sayesinde tohum, su, ilaç, gübre gibi kaynak kullanımlarına yüksek oranlarda tasarruf sağlanabilmektedir (Türker, 2024). Çalışmanın bulguları, Türkiye tarım sektörünün zayıf yönlerinden biri olarak yetersiz ve siyasileştirilebilen teşvik sistemini işaret etmektedir. Bu durum, Akhtar ve Pirzada (2014)'ün Pakistan tarım sektöründe tespit ettiği yapısal sorun ile örtüşmektedir: Devlet desteklerinin yetersizliği ve kaynak dağılımında siyasi nüfusun belirleyici olması, büyük çiftçilerin avantaj elde etmesine karşın küçük çiftçilerin sistem dışı kalmasına neden olmaktadır.

Kaynak yönetimi ve planlama konusu, katılımcılar tarafından doğal kaynakların korunmasında planlama eksikliği, plansız su ve toprak yönetimi ile plansız üretim olarak zayıf yönler kapsamında değerlendirilmiştir. Sosyoekonomik zayıflıklar bağlamında katılımcılar çiftçi yoksulluğu, gençlerin tarımdan kopması, çiftçinin kaynak

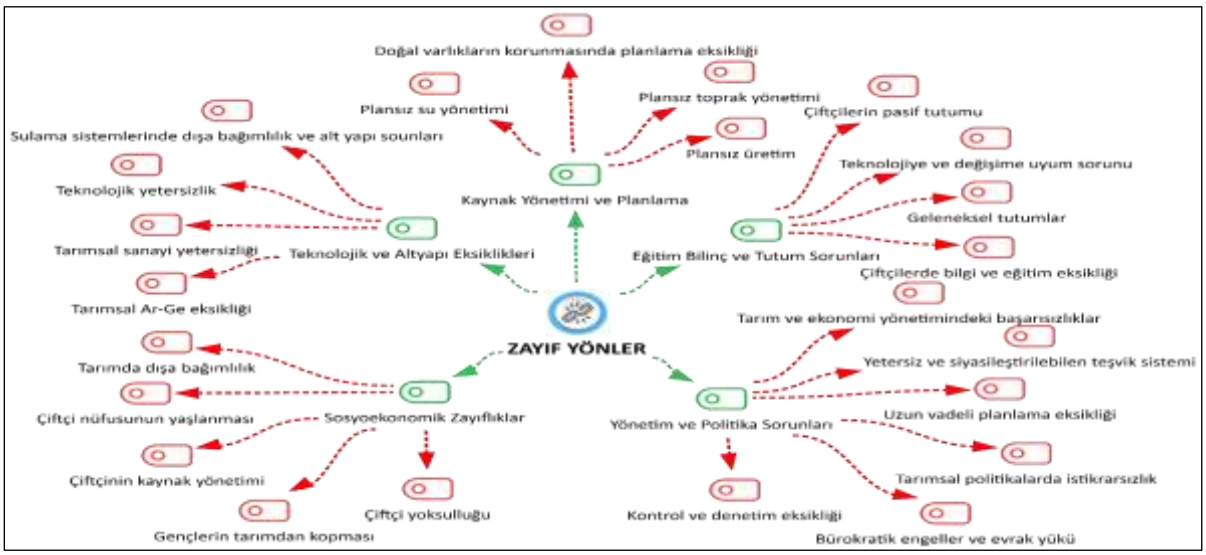
yönetimi, çiftçi nüfusun yaşlanması, tarımda dışa bağımlılık gibi zayıflıkları dile getirmiştir. Bazı katılımcının bu konudaki ifadeleri şöyledir:

K-05: "… Türkiye tarımı maalesef çok dışa bağımlı bir tarım haline geldi. O yüzden ekonominin kötü yönetiliyor olması, tarım ekonomisinin kötü yönetiliyor olması zayıf yön. Ondan sonra çiftçilerin yoksul olması ve eğitimsiz olması da gene zayıf yönlerinden."

K-15: "Öncelikle doğal varlıklarımızı korumayı bilmiyoruz. Bence en zayıf noktamız bu ve bizim başımızı derde sokacak konu da bu. Yani çok acilen bu doğru kararlar vermemiz gerekiyor. Yani bizim örneğin enerjiye mi ihtiyacımız var? HES yapalım… Suları enerji için kullanalım. Yoksa insanların gıda güvencesini mi sağlamaya ihtiyacımız var buna karar vermemiz gerekiyor yani bizi böyle bir gelecek beklediğinde de aslında öncelik yani o piramitte önce karnımızı doyurmak, o nedenle doğru kararlar vermemiz lazım."

Tarımsal üretim için su, toprak ve insan kaynağı önemli unsurlardır. Türkiye'de kaynaklardan çekilen suyun %70'inden fazlası tarımsal faaliyetlere ayrılmaktadır. 2000'li yılların başında %6 civarında olan modern sulama sistemlerinin günümüzde %35'lere kadar çıkartılması (TOB, 2024) önemli bir gelişmedir. Ancak, mevcut sulamanın halen %65 civarında üstü açık kanallar, salma sulama, körükle sulama gibi modern olmayan tekniklerle yapılıyor olması su yönetimi konusunda zayıflığı göstermekte dolayısıyla katılımcıların ifadelerini destekler niteliktedir. Modern sulama sistemlerinin, geleneksel sulama sitemlerine kıyasla sudan 2/3 oranına kadar tasarruf sağlanabilmektedir. Bu bağlamda tarımsal üretim için doğal kaynakların varlığı kadar bu kaynakların doğru bir yönetimle sürdürülebilirliğini sağlamak da önem arz etmektedir. Bu zayıflıklara ek olarak, literatürde tarım arazilerinin küçük ve parçalı olması da yapısal bir sorun olarak ele alınmaktadır. Çetin ve Canan (2024), mevcut yapısal sorunun kooperatif ve birlik örgütlenmeleri ile toprak reformu çalışmaları kapsamında birleştirilmesi gerektiğini ifade etmektedir. Bu tür bir birleştirme, hem tarımsal arazilerin tarım dışı amaçlarla kullanımı karşısında kollektif bir bilinç ve direnç oluşturacak hem de enerji ve girdi kullanımında önemli tasarruflar sağlayacaktır. Toprak bütünlüğünün sağlanması, büyük ölçekli ve verimli tarım uygulamalarının önünü açarak kaynak yönetimindeki zayıflıkları gidermeye yardımcı olabilir.

Türkiye'nin yaşlı nüfus oranı, Cumhuriyet tarihinde ilk kez 2023 verilerinde iki haneli düzeye (%10,2) çıkmış, 2024'te ise %10,6'ya ulaşarak artışını sürdürmüştür (TÜİK, 2025). Demografik yaşlanma eğilimine ek olarak, genç nüfusun tarımsal faaliyetlerden kopması ve eğitim veya iş olanakları nedeniyle kentlere yönelmesi, tarım sektöründeki çiftçi profilinin yaş ortalamasının ayrıca artmasına neden olmaktadır. Kredi Kayıt Bürosu (KKB)'nin saha araştırmasına göre 53,4 olan çiftçi yaş ortalaması, Türkiye Ziraat Odaları Birliği (TZOB)'un veri kayıt sistemine göre 58,1 civarındadır (KKB, 2023; TZOB, 2023). Her iki veri de tarım sektörünün geleceği için endişe verici bir tablo ortaya koymaktadır. Çetin ve Canan (2024), üreticilerin yaş ortalamasının yüksek olmasının yenilikçi modern üretim tekniklerinin benimsenmesi yerine geleneksel yöntemlerin ön planda tutulmasına yol açtığını belirtmektedir. Araştırmacılara göre bu durum, tarım sektörünün gelişimini engelleyen bir zayıflık olarak nitelenmektedir. Çiftçi yaşlanması sadece kronolojik olarak ifade edilebilecek bir sorun değil aynı zamanda babadan oğula geçen geleneksel üretim tekniğinin yavaş yavaş yok olması, tarımsal işgücünün zayıflaması demektir. Bunlara ek olarak, yaşlı üreticilerin teknolojik yeniliklere uyum konusunda zorluk yaşaması, bilgiye erişim olanaklarının kısıtlı olması, verimlilik ve rekabetçilik açısından ciddi sorunlar yaratmaktadır.



Şekil 2. Zayıf Yönler

Tema 3. Türkiye Tarımının Fırsatları

Şekil 3'te Türkiye tarımının fırsatlarını temsil eden alt temalar ve kategoriler gösterilmektedir. Buna göre, sosyoekonomik faktörler ve stratejik konum, katılımcılar tarafından tarım sektörü için fırsatlar olarak değerlendirilirmiştir. Bu kapsamda stratejik konum ve geniş pazar erişimi, kendine yetebilirlik ve üretim potansiyeli, kırsal kalkınma ve destekleme politikaları, genç çiftçilerin varlığı, tarımsal miras, sivil toplumun korumacı tutumu, alternatif tarım bilgi birikimi katılımcıların fırsat olarak görüş bildirdiği faktörler olmuştur. Bazı katılımcıların bu konudaki ifadeleri şöyledir:

K-12: "Yani biz Cumhuriyet olarak 100 yılı aştık ama yıllardır bu topraklarda tarım yapılıyor. Anadolu medeniyetin beşiği, Mezopotamya vs. Burası zaten zengin bir toprak. Bu bizim en büyük fırsatımız. Bunu doğru bir şekilde yani sürdürülebilir tarım sürdürülebilir su kullanımı vesaire gibi altı boşaltılmamış sürdürülebilirlik bizim için bir fırsat. Bunu doğru şekilde yapmamız belki de gerekiyor. Türkiye bu kadar avantaj ve potansiyele sahip lakin pazarda söz sahibi değil. Bu bizim için yine bir fırsattır."

K-10: "Bunun yanında az da olsa sivil toplum örgütünün (STK) aşırı su kullanımını ve toprak kullanımını talep eden sektörlere karşı bir direnci var. Bunlar her ne kadar mahkeme boyutunda kaybedilse de ama bir ses çıkarıyorlar. Böyle bir farkındalık yaratabiliyorlar. Pek de fazla fırsat kalmadı artık şu anda akademisyenler de maalesef bugünlerde popüler çöptür."

Türkiye'nin tarımsal mirası, binlerce yıllık geçmişiyle öne çıkmaktadır. Anadolu toprakları 10 bin yıl önce evcilleştirilmiş tahıl çeşitlerine sahipliği yapmış derin bir tarımsal mirasa sahiptir (Atar, 2017). Anadolu'daki bu değerli gen kaynakları ile binlerce yıllık tarımsal bilgi birikimi, Türkiye tarımın geleceği için önemli bir dayanak olarak görülmektedir. Ayrıca, Türkiye'nin yaklaşık %37'lik kırsal nüfusu, Avrupa ve ABD'nin kırsal nüfus oranlarının üzerindedir (Yavuz ve Dilek, 2019). Yoğun göç hareketlerine rağmen bu önemli kırsal nüfus varlığı, tarım sektörünün devamlılığı için son derece önemlidir. Bu potansiyel, kırsal turizm faaliyetleriyle daha da güçlendirilebilir. Kırsal turizm, tarım sektöründeki sorunlara karşı potansiyel bir çözüm olarak görülmektedir. Evrensel düzeyde uygulama zorlukları bulunsa da yerel ekonomileri canlandırma ve kültürel varlıkları koruma yönündeki katkıları sayesinde tarımsal sürdürülebilirlik için alternatif bir yol sunmaktadır. Avrupa'nın birçok ülkesinde kırsal turizmin başarılı örnekleri bulunmaktadır (Lane, 1994). Bu bağlamda, Türkiye'nin zengin tarımsal mirası ve geniş kırsal nüfusu, kırsal turizmle entegre edilerek hem yerel ekonomilere katkı sağlayabilir hem de tarımsal faaliyetlerin devamlılığına destek olabilir.

Sürdürülebilir tarım ve çevre dostu uygulamalar bağlamında agroekolojik tarım, geri dönüşüm ve sürdürülebilir kaynak kullanımı, yağmur suyu hasadı, yeşil alanların korunması ve arttırılması, azaltılmış toprak işleme, kuraklık dirençli bitki üretimi, organik tarım uygulamaları katılımcıların fırsat olarak ifade ettiği faktörler olmuştur. Katılımcıların bu konudaki ifadeleri şöyledir:

K-05: "Sebze meyveyi yani ekolojik olarak üretebilirsek daha yüksek fiyatlarla satabiliriz Avrupa'ya ve Arap ülkelerine. Bu da bir fırsat bu da bir fırsat olarak ele alınabilir. Agroekolojik tarıma geçtiğimiz takdirde bu sorunlardan kurtulacağımız da bir fırsat olarak yazılabilir."

K-09: "Şimdi mesela tamam toplam ölçekte baktığımız zaman kuraklık ama mesela bazen diyelim ki yağış kurak bölgede de çok ani hızlı bir şekilde gelişebiliyor ve buralarda da çoğu zaman sel niteliğine bürünüyor. Mesela buralar diyelim ki zaten su kaynakları sınırlı. İşte kentsel altyapı sistemleri var. Hani bu yağmur suyunu kanalizasyon sistemlerine geçmeden önce kullanıma sunacak şekilde birtakım projeler yapılıyor. Bununla ilgili özellikle gelişmiş ülkelerde birtakım teknolojiler, çabalar, girişimler söz konusu. Bunlar da bence kazandırabilir. Özellikle bu kurak bölgedeki şeyleri için mutlaka bunların düşünülmesi gerekiyor. Yani o yağmur suyunu böyle kullanıma kazandıracak şekilde projeler olabilir."

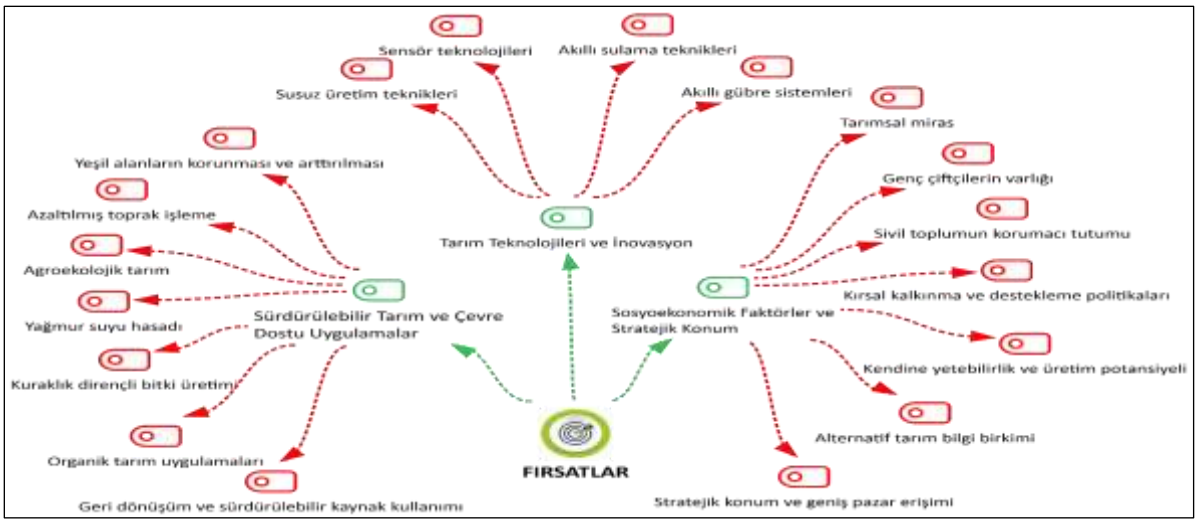
Tarımsal faaliyetler çevre üzerinde ciddi baskılar yaratmaktadır. Bu sebeple alternatif üretim teknikleri ve çevre dostu uygulamaları sürdürülebilir tarım için çok önemlidir. Avrupa Birliği (AB) on yıllardır tarım-çevre konulu önemli politikaları gündemleştirmektedir. Bu bağlamda Atış ve ark. (2024), Türkiye'nin uluslararası anlaşmalar ve AB uyum kapsamında tarımsal faaliyetlerin çevresel etkilerini hafifletecek ve iyi tarım uygulamalarını arttıracak birtakım düzenlemeleri yapması fırsat olarak görmektedir. Katılımcıların fırsat olarak değerlendirdiği agroekolojik tarım yüksek çevre hassasiyeti gözetilerek yapılan üretim yöntemlerini içermektedir. Agroekoloji, doğayla uyumlu bir alternatif tarımsal üretim yaklaşımıdır. Küçük ölçekli gıda üreticilerinin, köylülerin, yerli halkların ve çiftçi ailelerin sürdürülebilir ve adil bir gıda sistemindeki kritik rolünü ön plana çıkarmaya çalışır. Ayrıca, agroekolojinin temeli oluşturan bilgi, yer küre üzerindeki yaşayan yerli halkların ve küçük ölçekli tarım üreticilerin uygulamalarından ortaya çıktığını belirtmek lazım (Anderson ve Bruil, 2021). Agroekolojik yaklaşımın benimsediği az sürüm, anıza ekim veya doğrudan tohum ekme gibi minimum toprak işleme uygulamaları koruyucu tarım uygulamaları içerisinde yer almaktadır. Ekim nöbet ile malçlama denilen toprak yüzeyinin kuru otlarla örtülmesi, toprak neminin korunmasını ve toprağın yorulmamasını sağlamaktadır (Aydın ve Aktuz, 2023). Bu uygulamalar kurak dönemlerde çeşitli avantajlar sağlayan ekosistem tabanlı tarım uygulamalarıdır. Kuraklığa uyum konusunda genetik ıslah çalışmaları önemli bir yere sahiptir. Moleküler seçilim vasıtasıyla birçok üründe kuraklık koşullarını

tolere edebilen ve daha az su ihtiyacı olan tohum çeşitleri geliştirilebilmektedir. Her ne kadar tarım endüstrisi bu çalışmaları büyük ölçüde görmezden gelse de (Eisenstein, 2013) bu tohum çeşitlerinin kuraklık olaylarında geçimlik arazi sahipleri için bir çeşit sigorta görevi gördüğünü belirtmek gerekir. Su hasadı uygulamaları, kurak ve yarı kurak bölgelerde binlerce yıldır kullanılan bir yöntemdir. Babiller, İsrail, Tunus, Çin ve Amerika gibi bölgelerde eski medeniyetler tarafından inşa edilmiş su hasadı yapıları bulunmuştur. Bu teknikler, suyun kıt veya düzensiz olduğu alanlarda, özellikle mevsimsel kuraklık dönemlerinde başarıyla uygulanmış ve günümüzde de kurak ve yarı kurak iklim bölgelerinde kullanılmaktadır (Demir, 2024). Uzun vadeli gıda güvenliği için sürdürülebilir bir tarım sistemi hayati öneme sahiptir. Bu sistem, sentetik gübre ve pestisit gibi sürekli maliyet çıkartan girdi endüstrisine bağımlı olmayan ve çevresel şoklara karşı dayanıklı bir yapı sunmalıdır. Bilim insanları mantar ve bakteri kolonilerinden oluşan toprak mikrobiyomlarının bu süreçte hassas bir bir rol oynayabileceklerini ifade etmektedir. Bitkinin kök bölgesi yerleşen mikrobiyomlar bitki ile bir çeşit simbiyotik ilişkiye girerler. Topraktaki suyu çekerek bitki kökünün nemli kalmasını sağlarken karşılığında bitkiden birtakım besin maddeleri almaktadırlar. (East, 2013). Dolayısıyla, günümüzde aktif olarak kullanılan geleneksel tarım tekniklerinin, toprak işleme yoğunluğunun düşürülmesi, kimyasal uygulamalardan kaçınılması ve toprak neminin sürdürülebilir şekilde korunması gibi yöntemlerle kuraklık şartlarında önemli avantajlar sunduğu değerlendirilmektedir.

Tarım teknolojileri ve inovasyon başlığı altında akıllı sulama teknikleri, akıllı gübre teknikleri, sensör teknolojileri ile susuz üretim teknikleri faktörleri katılımcıların tarım sektörü için fırsat olarak nitelendiği uygulamalar olmuştur. Bir katılımcı bu konuyu şöyle ifade etmektedir:

K-13: "Bazı bölgelerde sulama sistemleri oldukça gelişmiş durumdadır. Covid sonrası özellikle tarımda dijitalleşme ve sensör teknolojileri, sulama, toprak nemi takibi gibi teknolojik alt yapıların kullanımı yaygınlaşmıştır. Bu teknolojiler ile su daha verimli kullanılarak, tarımsal verimliliği artırabiliriz"

Tarım teknolojisi sürekli değişim ve gelişim içerisindedir. Günümüzde hava durumu, toprak analizi, sulama, gübreleme, hastalıklar ve zararlılar ile mücadele, verim analizi gibi birçok konuda yeni tekniklerden ve teknolojik araçlardan faydalanılmaktadır. Sensörler vasıtasıyla herhangi bir bölgenin toprak, hava, su ve iklim bileşenleri analiz edilebilir bu bölgeye hangi ürünlerin ekilebileceği, ekilen ürünler için ise hangi bileşene ihtiyaç duyulduğu önceden tespit edilebilir ve olası bir olumsuzlukta erken müdahalede bulunabilmektedir. Ommani (2011), yeni teknolojilerin geliştirilmesi ve bunların tarımsal sektöründe kullanılmasının önemli fırsatlar sağladığını belirtmektedir. Literatürde teknolojik araçların ve yeni tekniklerin tarım sektörüne sağladığı avantajlar çeşitli araştırmalarla doğrulanmaktadır. Örneğin, Güman ve Günay (2024) sensör teknolojileri kullanarak bir arazide yaptıkları çalışmada arazi için yetiştirilmesi en uygun ürünü ve kullanılabilecek en uygun gübre çeşidini belirlemişlerdir. Akıllı tarım sistemleri, zaman, su ve diğer birçok girdinin etkin kullanımını sağlayarak önemli tasarruflar sunmaktadır (Sunar ve ark., 2024). Özellikle kuraklık koşullarında, bu teknolojiler su kullanımını optimize etmeleri ve gübre ile ilaç gibi kaynakların tüketimini sınırlandırmaları sayesinde maliyet ve işgücü açısından önemli fırsatlar sağlamaktadır. Nitekim, Sarıkaya (2022) tarafından yapılan bir araştırma, akıllı sulama tekniklerinin geleneksel yöntemlere kıyasla %40'a varan su tasarruf sağladığını ve aynı zamanda su kalitesini artırdığını ortaya koymuştur. Öte yandan, inovasyon fırsatları yalnızca üretim teknolojileriyle sınırlı kalmamaktadır. Çalışmanın bulgularına ek olarak Hosseini ve ark. (2019), tarımsal ürün ihracatında e-ticaret kanallarının stratejik rolüne dikkat çekmektedir. Geniş Pazar erişimi, rekabetçi fiyat avantajları ve maliyet tasarrufu gibi olanaklarla e-ticaret, tedarik zincirinde verimlilik artışı potansiyeli barındırmaktadır. Ancak bu potansiyelin gerçekleşmesi; devlet öncülüğündeki yasal düzenlemeler, veri güvenliği ve alt yapı iyileştirmelerine bağlıdır.



Şekil 3. Fırsatlar

Tema 4. Türkiye Tarımının Tehditleri

Şekil 4'te Türkiye tarımının tehditlerini temsil eden alt temalar ve kategoriler gösterilmektedir. Buna göre, çevresel ve iklimsel tehditler katılımcıların Türkiye tarım sektörü için yoğun olarak fikir belirttiği konu olmuştur. Özellikle iklim değişikliği ve küresel ısınma ile aşırı hava olayları ve afetler faktörleri sıkça tekrar edilmiştir. Biyolojik çeşitlilik kaybı, yeraltı su kaynaklarında tuzluluk riski, çölleşme, kimyasal kirlilik ve madencilik faaliyetleri tehdit olarak görülen diğer faktörler olmuştur. K-10 adlı katılımcının bu konudaki ifadesi şöyledir:

K-10: "… iklim değişikliğinden en çok etkilenen bölgelerin şu anda Türkiye'yi besleyen havzaların bulunduğu bölgeler olması. Bu çok kötü. Yani Ege havzaları, Akdeniz havzası ve Güneydoğudaki havzalar maalesef iklim değişikliğinden özellikle Ege başta çok etkilenecek. Bu demek ki sulu tarım üretim yapılan örneğin Türkiye'nin üzüm üretiminin, kuru üzüm üretiminin %90' ı Manisa- Gediz havzasında yapılır. Ege havzalarında yapılır. Bunun yok olacağını düşünürseniz önemli bir gıdayı kaybetmiş oluyoruz."

Türkiye, küresel iklim değişikliğinin riskli etkilerine açık bir ülkedir. Gözlemlenen ve öngörülen değişimler; su kıtlığı, kuraklık, ekolojik bozulma, orman yangınları, erozyon ve tarımsal verimlilikte düşüş gibi sonuçlara yol açmaktadır. Artan sıcaklıkların sıcak hava dalgası kaynaklı ölümlerde ve vektörel hastalıklarda artışa neden olması beklenmektedir (Turan, 2018). İklim değişikliğinin, özellikle su stresi yaşayan yarı kurak bölgelerde olmak üzere, kuraklıkların sıklığını ve şiddetini artırması öngörülmekte; bu duru ekosistemler, tarım ve toplumlar üzerinde yıkıcı etkiler yaratmaktadır (Cook ve ark., 2018). Türkiye'nin de içinde yer aldığı Akdeniz havzası, küresel ısınma kaynaklı aşırı hava olaylarının tarım sektörü için ciddi tehdit oluşturduğu bir bölgedir.

Tarım, ekonomik sürdürebilirlik, küresel trendler, gıda güvencesi gibi sebeplerden dolayı kamusal müdahalelere sıkça maruz kalan bir sektördür. Belirlenen ulusal hedeflere ulaşmak adına yapılan müdahaleler başarılı olabilmektedir. Ancak, aşırı toprak işleme, yoğun kimyasal girdi kullanımı ve tarımsal alanların doğal alanlara doğru genişlemesi gibi çevresel sorunları beraberinde getirmektedir (Atış ve ark., 2024) Türkiye'de tarımsal üretimde pestisit kullanımı giderek artmaktadır. Örneğin, 2000 yılında birim alanda kullanılan pestisit miktarı 1,27 kg iken, 2022 yılında bu miktar 2,22 kg'ye çıkmıştır. 2018 yılında bu miktar 2,59 kg ile iki katından bile fazla olmuştur. Avrupa ülkelerinde bu miktar 2000 yılında 1,47 kg iken 2022 yılında 1,64 olmuştur. Türkiye'nin kimyasal gübre kullanımı da benzer şekilde artış göstermiştir. 2000 yılında birim başına 79,20 kg gübre (azot, potasyum, fosfor bazlı) kullanılırken 2022 yılında bu miktar 97 kg'ye ulaşmıştır. Aynı yıllarda Avrupa ülkelerinde bu kimyasal gübrelerin kullanımı 65,12 kg'den 63,87 kg'ye düşmüştür (FAOStat, 2022). Bu veriler çalışmanın bulguları ile uyumludur. Türkiye tarım sektöründe kimyasal kullanımı son derece artmış ve sektörün geleceği için ciddi bir tehdit haline gelmiştir.

Su ve toprak yönetimi bağlamında katılımcılar tarafından tarım sektörü için tehdit olarak ifade edilen bazı durumlar sıralanmıştır: tarımsal alanların kaybı ve daralması, bilinçsiz su kullanımı ve sulama sorunları, su kaynaklarının azalması ve yönetimi, su ve toprak kalitesini bozulması, su krizleri ve sınır aşan su anlaşmazlıklar. Bu konuda bazı katılımcıların ifadeleri şöyledir:

K-03: "Bana göre en büyük tehdit tarımsal alanların küçülmesidir. Yüz ölçümü olarak da küçülmeye başlayacağız. Ne şekilde olacak bu, işin küresel ısınmanın sonuçlarından biri de deniz seviyesinin artmasıdır. Yarı kurak olan bölgelerin tamamen kuraklaşıp çöl iklimine kavuşması gibi Suriye sınırındaki Kızıltepe'den tutun Suruç'a Ceylanpınar'a Kilis'e kadar bu bölgeler zaten yarı kurak bölgelerdir. Buralar tamamen çöl iklimine dönüşecek ki yarı çöl iklimi var zaten. E buralar tamamen çölleşecek, yüz ölçümü olarak azalacak."

K-12: "Yine kuraklık kaynaklı su krizi yeterli tarımsal sulama için ayrılacak su miktarını bulamayacak olmamız da bizim için bir tehdit. Çünkü az önce bahsettiğimiz gibi içme suyu giderse ilk çekeceğimiz yer tabii. Yani su bulamama riski bir tehdit. Bölgesel sular az evvel söylediğim taşıma suyla değirmen döndürmeye çalışmak bizim için bir tehdit. Çünkü yarın bir gün o suyun fazla olduğu bölgede su ihtiyacı olsa adamlar diyecek ki "kardeş bize kadar var." Kusura bakma. Bittik o zaman biz yani…"

Dünyanın yaklaşık üçte ikisi suyla kaplıdır ve var olan suyun %97,5 okyanus, deniz ve diğer tuzlu kaynaklarından oluşmaktadır. Tatlı su miktarı ise yalnızca %2,5 civarındadır. Üstelik bu tatlı suyun %68'i buzullarda %30 ise yer altı kaynaklarında saklı bulunmaktadır. Yeraltı kaynakları hesaba katılmadığında kolay erişebildiğimiz tatlı su oranı ise sadece %0,3 civarındaki yüzey su kaynaklarıdır (Khilchevskyi ve Karamushka, 2021). Türkiye, su stresi altında olan bir ülkedir. Falkenmark (1992), tarafından geliştirilmiş ve küresel çapta yaygın olarak kabul görmüş göstergeye göre, nüfus başına düşen su miktarının yıllık 1000-1700 m3 arasında olması su stresini işaret etmektedir. Türkiye'nin kişi başına düşen su miktarı uzun yıllardır düşüş eğilimdedir. 2000 yılında nüfus başına düşen miktar 1652 m3 civarında iken 2020 yılında 1346 m3 e kadar düşmüştür (Sarış, 2021). Tarım sektörü, Türkiye'de de tatlı suyun en fazla kullanıldığı sektördür. Günümüz şartlarında sektörel kaynak kullanımı ve yönetimi olası kuraklık durumları için önemli tehditler barındırmaktadır. En önemli hususlardan biri olan kayıp su oranında Türkiye, gelişmiş ülkelerin çok gerisinde olmasıdır. Gelişmiş ülkelerde %8-24 arasında değişen su kayıp oranı Türkiye'de %33,54 civarındadır. Su kayıp kaçak oranının azaltılması adına uygulamaya konulan ve 2033 yılına kadar su kayıp oranının en fazla %25, 2040 yılına kadar ise en fazla %10 olacak şekilde hedeflerin belirlenmesi ve bu hedeflerin yönetmelik ile yasal bir çerçeveye dayandırılması son derece önemlidir (TOB, 2022; 2023). Ancak çalışmaya katılan uzmanların belirttiği denetim-kontrol zayıflıkları hedeflere ulaşma konusunda birtakım tereddütleri beraberinde getirmektedir. Öte yandan Gediz, Menderes, Ergene, Meriç, Susurluk, Sakarya nehirleri ile Susurluk ve Ankara çaylarında kirliliğin tehlikeli boyutlara ulaşmış olması (TZOB, 2019) tatlı su kaynaklarını baskılayan bir diğer tehdittir. Hızlı önlem alınmadığı takdirde önemli su kaynaklarını kaybetme riskinin yanında ciddi ekolojik tahribatlarla karşı karşıya kalınabilir. Ayrıca, Aydın ve Aktüz (2023) kaynak kullanımı ile ilgili önemli bir konuya dikkat çekmektedir. Su kaynaklarının yetersiz olduğu bölgelere uzak mesafelerden su taşınması durumlarımda sızıntı ve buharlaşma kaynaklı su kaybının olduğu, bu durumlarda açık sistem sulama kanallarının su boruları vasıtasıyla kapalı sistemlere dönüştürülmesi gerektiğini belirtilmektedir. Yerkürede tatlı su miktarının son derece sınırlı olduğu ve mevcut su kaynaklarının ülkelere eşit bir şekilde dağılım göstermediği açıktır. Bu bağlamda sıkı ve etkili bir su yönetimi politikası kısıtlı su kaynağına sahip ülkeler için bir çeşit zorunluluk haline gelmiştir. Türkiye'de sektörel kaynak kullanımı ve kaynak yönetimi ile ilgi önemli sorunlar yaşanmaktadır. Özellikle su kullanımında az tüket, kullandığın suyu başka işlemlerde yeniden kullan, gerekiyorsa kirlenmiş suyu geri dönüştür disiplinini bir kültür haline getirmek gerekir. Aksi takdirde hali hazırda su stresi altında olan Türkiye'nin gelecekte bir su krizi ile karşı karşıya kalması ciddi bir olasılıktır. Su kaynaklarının etkin yönetiminin yanı sıra, tarımsal üretim kapasitesini tehdit eden bir diğer kritik sorun da arazi kullanımındaki plansız dönüşümdür. Nitekim, kentleşme baskısı altındaki arazilerinin, konut inşaatları ve endüstriyel altyapıya dönüştürülmesi, tarımsal üretim üzerinde ciddi bir tehdit oluşturmaktadır. Bu tehdidin azaltılması için merkezi ve yerel paydaşların, yönetişim mekanizmaları kapsamında; yasal düzenlemeler, finansal teşvikler, altyapı optimizasyonu, su-arazi bütünleşik yönetimi, halk sağlığı ve çevresel sürdürülebilirlik eksenlerinde stratejiler geliştirilmesi önem arz etmektedir. Ramaloo ve ark. (2018), bu bağlamda kentsel tarımın yaygınlaştırılmasının, gıda güvencesinin sağlanmasına ve yoksulluğun azaltılmasına katkı sunabileceğini öne sürmektedir.

Sosyo-politik dinamikler başlığı altında katılımcılar kentleşme ve uyum sorunları, iklimsel göçler ve toplumsal huzursuzluk, politik istikrarsızlık ve ve dış etkilenebilirlik, göç politikaları, tarım işgücü azalması ve dışa göç, tarımda yanlış inançlar ve iklim inkarcılığı gibi faktörleri tarım sektörü için tehdit olarak belirtmiştir. Bir katılımcının bu konudaki ifadeleri şöyledir:

K-11: "Yani göçmenlerin kendisinden bağımsız olarak göç politikaları bir tehdit. Çünkü orada hani kişiye yönelik bir şey kesinlikle yok ama göçe yönelik politikalar ciddi bir tehdit. Ve aslında bizim iklim inkarcılığı dediğimiz şey büyük bir tehdit. Yani bu iklim değişikliğinin olmadığına yönelik algı …"

Tarih boyunca birçok itici veya çekici güç, insanların kalıcı veya geçici yer değiştirmesine, bir başka deyişle göç etmesine neden olmuştur. Günümüzde yaşanan göç olaylarında iklim değişikliği (Bilik, 2023) ve onunla bağlantılı afetler, aşırı hava olayları en önemli itici etkenler arasında değerlendirilmektedir. Cattaneo ve ark. (2019), göçü tetikleyen yavaş gelişimli olaylar olarak küresel ısınma, kuraklık ve arazi bozulumunu; hızlı gelişimli olaylar olarak sel, fırtına ve kasırgaları örneklendirmiştir. Bu bağlamda, iklim değişikliğinin tetiklediği göçler üzerine yapılan araştırmalar, gelecekteki olası senaryolar hakkında önemli bilgiler sunmaktadır. Smirnov ve ark. (2023) araştırmalarında çalıştırdıkları simülasyon bulgularına dayanarak, gelecekte kuraklık kaynaklı göçlerin en yoğun olarak yaşanacağı ülkelerin Mali, Mısır ve Türkiye olacağını ifade etmektedir. Türkiye'nin bu küresel iklim tablosundaki yeri, bölgesel çalışmalarla da desteklenmektedir. Tekin ve Deniz (2024), çalışmalarında yağış düzensizlikleri ve sıcaklık artışları ile beraber aşırı insan müdahalesinin su kaynaklarını yok edebildiğini vurgulamış

ve sonuç olarak kırsal yerleşim yerlerinde %24,6'lara varan nüfus azalışlarını tespit etmişlerdir. Öte yandan sosyoekonomik koşulları ve Avrupa'ya geçiş için önemli bir rotada olması sebebiyle Türkiye, farklı statülerde göçmenlerin uğrak bir noktası olmuştur. Türkiye'nin iç dinamikleri ve kıt kaynakları göz önüne alındığında kayıtlı-kayıtsız farklı milletlerden milyonlarca farklı statüdeki göçmenin varlığı gelecek için birtakım sosyoekonomik tehditleri barındırdığı söylenebilir (An ve ark., 2021)

Bu bağlamda, tarımsal üretimin sürdürülebilirliği açısından kritik bir sorun olarak genç nüfusun kırsal alanlardan göçü öne çıkmaktadır. Kırsal alanlarda yeterli ekonomik ve sosyal olanakların kısıtlı olması, genç nüfusun tarım sektöründen uzaklaşmasına ve tarımın geleceğinin tehdit altına girmesine yol açmaktadır. Çetin ve Canan (2024), genç bireylerin tarımda kalıcılığını sağlamak amacıyla ilçe ve köy ölçeğinde modern tarımsal tesislerin kurulması ile çeşitli sosyal ve kültürel olanakların yaratılmasının gerekliliğini vurgulamaktadır. Bu durum, iklim değişikliğinin neden olduğu çevresel itici faktörlerin yanı sıra, sosyoekonomik yetersizliklerin de iç göçü tetikleyici bir unsur olduğunu göstermektedir.

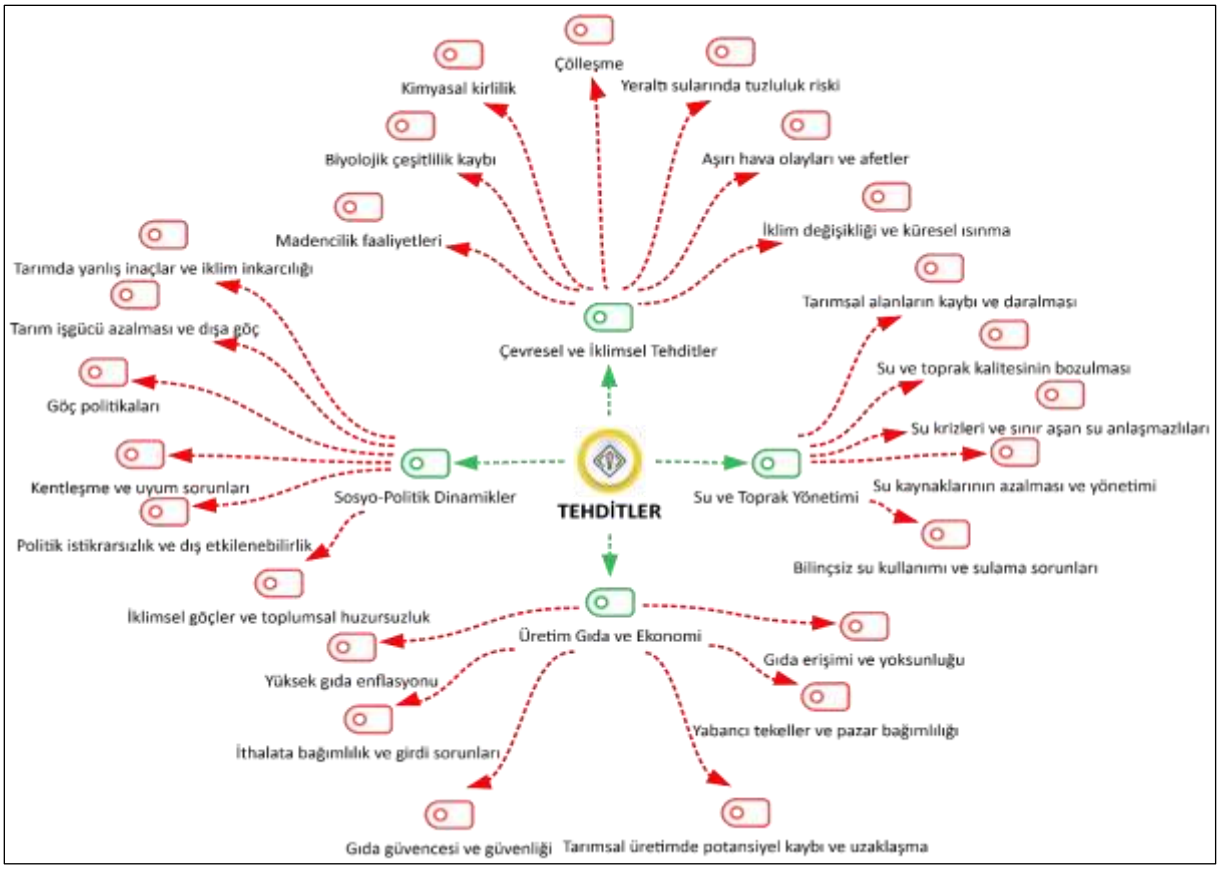
Çalışmamızın bulguları, ithalat bağımlılığı ve girdi sorunlarının sektör için ciddi bir tehdit oluşturduğunu açıkça ortaya koymaktadır. Aktar ve Pirzada (2014) tarafından belirtildiği üzere, ithalat kökenli kimyasal girdilerin yabancı şirketlerin tekelinde olması, söz konusu şirketlerin faaliyet gösterdikleri ülkelerin gelişiminden ziyade yalnızca kendi çıkarlarını öncelemelerine ve girdi fiyatlarını kendi istekleri doğrultusunda belirlemelerine olanak tanımaktadır. Bu durum, çiftçilerin yüksek fiyatlarla girdi temin etmesine neden olmakta ve tarımsal üretim maliyetlerini artırarak tarım sektöründeki kırılganlığı derinleştirmektedir.

Üretim gıda ve ekonomi başlığı altında katılımcılar gıda güvencesi ve güvenliği, tarımsal üretimde potansiyel kaybı ve uzaklaşma, ithalatta bağımlılık ve girdi sorunları, yüksek gıda enflasyonu, gıda erişimi ve yoksunluğu yabancı tekeller ve pazar bağımlılığı faktörlerini tarım sektörü için birer tehdit olarak ifade etmektedir. Bazı katılımcıları bu konuda görüşleri şöyledir:

K-05: "Büyük şirketler hâkim oluyorlar ekonomiye. Yani mesela fındık yani çok iyi bir üründür. Hani öyle fazla bir girdiyle de üretilmez yani. Ama buna rağmen xxx gibi firma buna hâkim oluyor. Fiyatları belirliyor bilmem ne bilmem ne. Yani tehditler işte böyle. Yani tehditler dünyada işte Amerikan firmaları olsun büyük ölçüde uyguladıkları tarım politikalarıyla ve Amerikan devletinin de uyguladığı tarım politikalarıyla işte "damping" yapıyorlar. Dampingler, Türkiye tarımında bazı ürünleri çöküşe götürüyor, buğday bunlardan biri yani bazı ürünleri üretemez hale gelebiliriz."

Çalışma bulgularında öne çıkan gıda yoksunluğu, erişim sorunları ve gıda güvencesizliği tehditleri, küresel ölçekteki dramatik tablo ile örtüşmektedir. Fischer ve ark. (2002)'nın vurguladığı gibi, dünyada yüz milyonlarca kişi kronik kronik açlıkla ve yoksullukla mücadele ederken; yoksulluğun %75'i tarıma bağlı kırsal kesimde yoğunlaşmaktadır. Prosekov ve Ivanova (2018)'ya göre Birleşmiş Milletler (BM) gibi resmî kurumlar ve sivil toplum örgütlerini yoğun çabalarına rağmen, küresel ölçekte yetersiz beslenme, açlık, yoksulluk ve gıda güvencesizliği tehlikeli seviyelerde devam etmektedir.

Türkiye'deki sağlıklı beslenme şartlarını karşılayamayan 7,4 milyon bireyin olması, küresel gıda krizin bir yansımasıdır (FAO vd. 2024). Bu tablo, gıda enflasyonunda ulaşılan tarihi değerlerle (2022'de OECD-AB ortalamasının 4.77 katı) ve dünyada 4. Sıradaki yüksek enflasyon düzeyiyle doğrudan bağlantılıdır. Gc ve Ghimire (2018) yüksek gıda enflasyonunu ayrıca aracılar zincirinin uzun ve güçlü yapısıyla ilişkilendirmektedir. Araştırmacılara göre, tarım-gıda sistemlerinde çok fazla aracının olması çiftçinin ürününü düşük fiyatlardan satmasına, tüketicinin de yüksek fiyatlardan ürün almasına yol açarak enflasyonu derinleştirdiğini vurgulamaktadır. Akın ve Demirkol küresel gıda fiyatlarının düşüşe geçtiği bir zamanda Türkiye'deki bu anomalini ivedi bir şekilde araştırılması gereken kritik bir sorun olarak değerlendirmektedir. Ayrıca Güran (2024), yakın tarihte yaptığı çalışmasında Türkiye'nin iklim değişikliği etkilenebilirlik düzeyini göz önünde bulundurarak gelecekte gıda güvenliği, gıda fiyatları ve gıdaya erişim konusunda olumsuzluklar yaşanabileceğini belirtmektedir.



Şekil 4. Tema- Tehditler

SONUÇLAR VE ÖNERİLER

Tarım sektörü, binlerce yıldır toplumların beslenme ihtiyacını sağlayan en önemli sektör olmuştur. Ancak, günümüzde tarımın geleceğini önemli derece belirsizleştiren doğa kökenli ve insan kaynaklı tehditler bulunmaktadır. Kuraklık, tarımsal sürdürebilirliği tehdit eden unsurların başında gelmektedir. IPCC raporlarına göre Türkiye'de gelecekte şiddetli kuraklık olayları yaşanacaktır. Aynı raporlarda kuraklıklardan en fazla etkilenebilecek sektörlerden biri olarak tarım sektörüne dikkat çekilmiştir. Bu çalışmada, tarım sektörünün sürdürülebilirliğini riske atan kuraklık tehditlerine yönelik olarak, sektörü değerlendirmek için SWOT analizi yapılmıştır. Bu kapsamda uzman görüşmelerine başvurulmuştur.

Çalışmanın bulgularına göre Türkiye sahip olduğu iklimi, coğrafyası, biyolojik çeşitliliği ve üretim potansiyeli bakımından güçlü konumdadır. Zengin bitki ve hayvan türlerinin varlığı önemli avantajlar sağlamaktadır. Olumsuz koşullara karşı esnetilebilen geniş ürün yelpazesi ile değişken iklim koşullarına uyumlu bitki varlığı sektörü güçlü kılmaktadır. Matematiksel ve özel konumu farklı iklim tiplerinin görülmesine ve dört mevsimin yaşanabilmesine imkân sağlamakta, çeşitli ve verimli toprak yapısının yanı sıra geniş arazilerin varlığı yıl boyu ekim potansiyelini barındırmaktadır. Anadolu topraklarının kadim tarımsal mirası sektörü güçlü kılan önemli unsurlardandır. Yerli tohumların varlığı ve kırsal bölge çiftçisinin doğayı koruma tutumu, tarımsal alanların korunması ve tarımsal faaliyetlerin sürdürebilirliği açısından önem arz etmektedir. Uzun yıllardan beri devam etmekte olan kent yönlü göç hareketlerine rağmen, Türkiye'nin OECD ve diğer Avrupa ülkelerine kıyasla önemli bir kırsal nüfusa ve genç iç gücüne sahip olması sektörünün güçlü yönlerini temsil etmektedir.

Yönetim ve politika sorunları tarım sektörü için yoğun olarak öne çıkan zayıf yönlerdir. Ekonomi yönetimindeki sorunlar tarım sektöründe yoğun olarak hissedilmektedir. Uzun vadeli planlama eksikliğinin yanı sıra mevcut planlamaların sıklıkla değişmesi istikrasız bir yönetimi işaret etmekte ve sektörün zayıf yönünü ortaya koymaktadır. Ayrıca, tarımsal destek ve teşviklerin yetersiz oluşu, bazı bölgelerde siyasi talep ve beklentilerle özdeşleşmesi algısının varlığı hem tarım otoritesi çevreleri ile hem de akademik çevrelerle tartışılması gereken hassas bir konudur. Bunların yanında gerekli olan yoğun bürokratik işlemler ve evrak yükü çiftçilerin destek ve teşvik mekanizmalarından faydalanmasını engelleyebilmektedir. Gerek saha çalışmalarında gerekse de kurum faaliyetlerinde gözlemlenen yetersiz kontrol ve denetleme süreçleri uygulanan politikaların etkisini zayıflatmaktadır.

Türkiye tarım sektörünün temel zayıflıkları arasında, çiftçilerin yenilikçi yaklaşımlara direnci ve eğitim eksikliği gösterilmektedir. Ayrıca yetersiz yatırım, finansman ve teknik destek; ileri teknoloji ve mekanizasyon yetersizliği öne çıkan diğer zayıf yönlerdir. Bu faktörler tarım sektörünün rekabet gücünü düşürmektedir. Çiftçilerin yaşlanması, genç nüfusun ise kısıtlı sosyal ve ekonomik olanaklar nedeniyle tarımdan uzaklaşması tarımsal iş gücünü zayıf düşürmektedir. Ek olarak, yüksek girdi maliyetleriyle düşük ürün fiyatları arasındaki makas, karlılık eşiğini yok ederek tarımsal yoksulluğu yapısal bir olguya dönüştürmektedir. Söz konusu dinamiklerin tetiklediği rekabet kaybı, demografik kırılganlık ve ekonomik sürdürülemezlik, tarım sektörünü çok boyutlu bir yapısal kriz sarmalına sürüklemektedir.

Türkiye'nin sahip olduğu tarımsal miras ve bu mirasın korunması adına sivil toplumun doğaya zarar veren büyük şirketlere karşı gösterdiği mücadeleler sektörün dirençliliği için önemli fırsatlar olarak değerlendirilmektedir. Kırsaldaki genç nüfusun göç etme eğilimine rağmen, halen tarımsal faaliyetlere katılan genç çiftçilerin varlığı sektörün geleceği için çok değerlidir. Bu noktada merkezi yönetimin uyguladığı kırsal kalkınma ve destekleme politikalarının etkisi yadsınamaz ancak destekleme kapsamlarının genişletilmesi ve sosyal-ekonomik imkanlarının çeşitlendirilmesi halinde genç nüfusun kırsalda sürekli olmasını sağlayabilecektir. Türkiye tarımsal üretimde kendine yeten bir konumdadır. Bunun yanı sıra yüksek gelirli Avrupa ve Arap yarımadası devletlerine yakın bir coğrafyada yer almaktadır. Mevcut stratejik konumu geniş bir pazara hitap etme fırsatını sağlamaktadır. Agroekolojik tarım teknikleri, organik tarım, azaltılmış toprak işleme, yeşil alanların korunması gibi sürdürülebilir tarım ve çevre dostu yaklaşımlar kar odaklı endüstriyel tarım uygulamalarının alternatifleri olarak düşünülmektedir. Geri dönüşüm ve sürdürebilir kaynak kullanımı ile beraber yaygınlaşmaya başlayan yağmur suyu hasadı teknikleri önemli uygulamalardır. Bu uygulamalar yağışların az olduğu kuraklık dönemlerde su kaynakları üzerindeki baskıyı hafifletmek adına değerlidir. Öte yandan susuz tarım yöntemleri, sensör destekli akıllı sulama ve gübreleme gibi teknolojiler sadece verimli kaynak kullanımını sağlamakla kalmaz, aynı zamanda toprak, su, hava gibi unsurları aşırı kirlilikten koruyabilmektedir. Bu sistemlerin Türkiye tarımında yaygınlaşması için gerekli maddi ve teknik desteklerin sağlanması sektörün geleceği için büyük fırsatlar barındırmaktadır.

IPCC senaryolarına göre Türkiye, iklim değişikliğinden en fazla etkilenecek ülkeler arasındadır. Tarım sektörü kuraklık, orman yangınları, don ve taşkınlar gibi çoklu iklim tehditleriyle karşı karşıyadır. Bu etkiler bölgesel farklılıklar göstermekte; Akdeniz ve Ege'de biyoçeşitlilik kaybı ile yer altı sularında tuzlanma, İç ve Güneydoğu Anadolu'da ise çölleşme riski öne çıkmaktadır. Özellikle Ege'nin vadi konumlu havzalarında aşırı su çekimi, tuzlu su girişimi gibi hidrolojik riskleri ortaya çıkarmaktadır. Bunlarla beraber bilinçsiz kimyasal ilaç ve gübre kullanımı, madencilik faaliyetleri ile tarım arazilerinin tarım dışı amaçlarla kullanımı insan kaynaklı çevresel baskıları yoğunlaştırmaktadır.

Su stresi altındaki Türkiye'de su yönetimdeki problemler, bilinçsiz kullanım ve kirlilik sebebiyle su krizi riski artmaktadır. Sınır aşan suların jeopolitik gelirim potansiyeli, tarımın su erişimde öncelik kaybetme tehlikesini barındırmaktadır. Kırsaldan kente iklim göçü, tarımsal işgücü kaybı erimesini ve kentsel alanlarda huzursuzluk risklerini tetiklerken; neoliberal politikaların beslediği ithalat bağımlılığı ve gıda enflasyonu ile küresel iklim iş birliğindeki belirsizlikler, tarımsal üretim şoklarına karşı zarar görebilirliği derinleştirmektedir. Ayrıca, birbirini besleyen bu kümülatif dinamikler, gıda güvencesi açısından sistemsel bir tehdit oluşturmaktadır.

Sonuç olarak, çalışmanın bulguları ile güncel veriler ve literatür bulguları beraber değerlendirildiğinde, Türkiye'nin iklimi, coğrafyası, doğal kaynakları ve biyoçeşitliliği tarım sektörünü güçlü kılmaktadır. Ayrıca sahip olduğu kadim tarımsal mirası, alternatif üretim teknikleri ve genç nüfusu bakımından önemli fırsatlara sahiptir. Ancak, zayıf kurumsal yapı, teknoloji ve altyapı eksiklikleri, kısa vadeli ve istikrarsız politikalar, bilinçsiz kaynak kullanımı, eğitimsiz üreticilerin fazla oluşu sektör için önemli zayıflıklar olarak göze çarpmaktadır. Bunlarla beraber başta küresel ısınma ve iklim değişikliği olmak üzere çevresel ve iklimsel tehditler, göç, gıda güvencesizliği, yüksek ithalat bağımlılığı tarımsal üretimin geleceğini ve sürdürebilirliğini tehdit etmektedir.

Bu kapsamda, tarımsal üretimde iklim hassasiyetli, uzun vadeli ve piyasa istikrarını gözeten politikaların kurumsallaştırılması kritiktir. Bu politikaların etkinliği için, saha uygulamalarının izlenmesi, denetim mekanizmalarının güçlendirilmesi ve destek sistemlerindeki bürokratik prosedürlerin köklü bir şekilde sadeleştirilmesi doğrudan ilişkilidir. Kaynak verimliliği ve sürdürülebilirlik bağlamında; üreticilerin çevre-duyarlı üretim teknikleri, iklim uyumu ve hassas tarım teknolojileri konusunda bilinçlendirilmesi ve desteklenmesi, aynı zamanda dijital dönüşümün teşvik edilmesi amacıyla Ar-Ge altyapısına stratejik düzeyde yatırımlar yapılması elzemdir. Tarımsal demografik kırılganlığın önlenmesi amacıyla, kırsal sosyokültürel olanakların çeşitlendirilmesi, eğitim-sağlık hizmetlerinin iyileştirilmesi gibi genç nüfusun tarımda kalıcılığını sağlayacak projeler hayata geçirilmelidir. İthalat bağımlılığın azaltılması için ise yerli girdi üretimi, üretici birliklerinin finansal erişiminin desteklenmesi ve öz sermayeli tesislerin kurulması zorunludur. Ekolojik sürdürülebilirlik perspektifinde; su ve toprak kirliliğinin önlenmesi, atık geri kullanımının yaygınlaştırılması ve kaynak tahribatına karşı caydırıcı

yaptırımlar uygulanması önemlidir. Nihai hedef, coğrafi konum, genç nüfus ve doğal kaynaklar gibi stratejik avantajların, multidisipliner politikalar aracılığıyla ulusal ve küresel ölçekte rekabet gücüne dönüştürülmesidir.

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