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**Serological and Molecular Detection of Single and Mixed Infections Symptomatology Associated with Potato Viruses Infecting Commercial Potato in Punjab Province, Pakistan**

Pakistan'ın Pencap Eyaletinde Ticari Patatesleri Etkileyen Patates Virüsleriyle İlişkili Tek ve Karışık Enfeksiyonların Semptomatolojisinin Serolojik ve Moleküler Tespiti

Samina YASMIN<sup>1\*</sup>, Mukaddes KAYIM<sup>2</sup>

**Abstract**

Potato is an important source of food in developing countries, and potato viruses have been a major constraint on sustainable production of the potato crop in Sialkot, Punjab Province, Pakistan. During February 2021, a survey of nine commercial potato fields was conducted to determine the incidence of PVY, PVX, and PLRV, respectively. The results of serological and RT-PCR assays indicated that PVX was not detected in any of the fields. PVY and PLRV were dominant in all fields with infection levels up to 63.15% and 45.83% respectively. The incidence of co-infection of potato with PVY and PLRV was 8.3%. The RT-PCR was the most reliable method for the detection and identification of viruses. The coat protein sequences of PVY-SKT<sub>1</sub>, PVY-SKT<sub>2</sub>, PLRV-SKT<sub>1</sub> and PLRV-SKT<sub>2</sub> were deposited in the Genbank database and assigned the accession numbers MW881191, MW881192, MW881193, and MW881194. The BLASTn search indicated PVY sequence shared the greatest similar score, at 99% similarity, with PVY isolates from China (HM036202.1) and Kashmir (KY851109.1). The PLRV sequence was most closely related to PLRV-Pakistan (MF276872.1) (99.8%) and China (KR051180.1) (99%) isolates. The results of co-inoculation experiments corroborated previous reports that infection of potato by multiple viruses dramatically increased disease severity (50-70%), compared to single virus infections (45-65%). The ELISA and RT-PCR results were confirmatory in that virus was detected in plants by serological and molecular methods, respectively. The prevalence of single and mixed PVY and PLRV infections in commercial potato fields underscores the need for routine virus indexing to foster routine planting of virus-free seed tubers.

**Keywords:** Molecular detection, Potato leafroll virus, Potato virus Y, Plant virus co-infection, Serology

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## Öz

Patates, gelişmekte olan ülkelerde önemli bir gıda kaynağıdır ve patates virüsleri, Pakistan'ın Pencap Eyaleti, Sialkot bölgesindeki patates üretiminin sürdürülebilirliğini ciddi şekilde kısıtlamaktadır. Şubat 2021'de, PVY, PVX ve PLRV virüslerinin görülme sıklığını belirlemek amacıyla dokuz ticari patates tarlasında bir tarama yapılmıştır. Serolojik ve RT-PCR analiz sonuçları, PVX'in hiçbir tarlada tespit edilmediğini göstermiştir. PVY ve PLRV'nin ise tüm tarlalarda baskın olduğu ve enfeksiyon oranlarının sırasıyla %63,15 ve %45,83'e ulaştığı tespit edilmiştir. PVY ve PLRV'nin birlikte enfekte ettiği patateslerin oranı %8,3 olarak belirlenmiştir. RT-PCR, virüslerin tespiti ve tanımlanmasında en güvenilir yöntem olarak öne çıkmıştır. PVY-SKT1, PVY-SKT2, PLRV-SKT1 ve PLRV-SKT2'ye ait dış kılıf proteini dizileri GenBank veri tabanına kaydedilmiş ve sırasıyla MW881191, MW881192, MW881193 ve MW881194 erişim numaraları atanmıştır. BLASTn analizi, PVY dizisinin Çin'den (HM036202.1) ve Keşmir'den (KY851109.1) izolatlarla %99 oranında benzerlik gösterdiğini ortaya koymuştur. PLRV dizisinin ise Pakistan'dan (MF276872.1) %99,8 ve Çin'den (KR051180.1) %99 oranında benzerlik gösterdiği belirlenmiştir. Ortak enfeksiyon deneylerinin sonuçları, önceki raporlarla uyumlu olarak, birden fazla virüsün patatese bulaşmasının, tek bir virüsle enfeksiyona kıyasla hastalık şiddetini (%50-70) önemli ölçüde artırdığını doğrulamıştır (tek virüs enfeksiyonlarında %45-65). ELISA ve RT-PCR sonuçları, bitkilerde virüslerin serolojik ve moleküler yöntemlerle tespit edildiğini doğrulamıştır. Ticari patates tarlalarındaki tekli ve karışık PVY ve PLRV enfeksiyonlarının yaygınlığı, virüssüz tohum yumrularının düzenli olarak dikimini teşvik etmek için rutin virüs indeksleme uygulamalarının önemini vurgulamaktadır.

**Anahtar Kelimeler:** Moleküler tespit, Patates yaprak kıvrıcıklığı virüsü, Patates virüsü Y, Bitki virüsü ko-enfeksiyonu, Seroloji

## 1. Introduction

Potato (*Solanum tuberosum*) is an important crop in terms of human consumption and nutrition, ranks third after wheat and rice (Devaux, et al., 2014). Countries in tropical and sub-tropical climates account for half of the production of the world's potato crop, which is affected by many abiotic and biotic factors. Among the biotic factors, viruses are of among the most important based on distribution, incidence, and economic loss. More than 50 viruses and two viroids have been reported to infect potatoes. However, the viruses that pose the greatest threat to the potato crop (Kreuze et al., 2020; Harahagazwe et al., 2018) are *Potato virus Y* (PVY) (genus, *Potyvirus*; family, *Potyvirdae*) and *Potato leafroll virus* (PLRV) (genus, *Polerovirus*; Luteoviridae), causing up to 80% yield loss. *Potato virus X* (PVX) (genus, *Potexvirus*; family Alfaflexiviridae) is less prevalent than PVY and PLRV and causes minor (10-25%) tuber infections (Mughal et al., 1981). These viruses may occur as a single or mixed infection of potato plants, and co-infection often results in greater disease severity, due to synergistic effects (Garcia-Cano et al., 2006). A survey was conducted to quantify the incidence of RNA viruses infecting potatoes in Pakistan. The results suggest the prevalence of multiple viruses in all surveyed areas with PVS, PVX, and PVY exhibiting infection levels of upto 50%. Co-infections were detected, with highest incidence recorded at 15.5% for PVX and PVS (Hameed et al., 2014).

Potato is vegetatively propagated, making it vulnerable to plant virus spread when seed tubers are infected at time of planting. Further, the rate of seedling emergence is reduced in virus-infected seed tubers and infected potato plants that emerge and survive often exhibit reduced vigor and yield (Wright and Bishop 1981; Kumar et al., 2017). The availability of virus-free potato seed tubers can be a barrier to sustainable potato production (Wales et al., 2008), making sensitive, accurate detection of potato viruses crucial for the production of virus-free seed tubers. When resources are limited ELISA (enzyme-linked immunosorbent assay) is a reliable detection method for the detection of potato viruses (Önder and Korkmaz, 2008; Wrobel, 2014; Ilbagi and Geyik, 2014). The most optimal virus detection assays offer sensitive, specific detection and rapid turn-around time. Reverse transcription polymerase chain reaction (RT-PCR) is more than 100 times more sensitive compared to ELISA (Dietgen, 2002). The objective of this study was to examine the prevalence of the potato viruses PLRV, PVX, and PVY in commercial potato fields in Sialkot, Punjab province, Pakistan.

## 2. Materials and Methods

### 2.1. Sample collection

During 2021, surveys were conducted in commercial potato fields of Pasrur, Sambrial and Daska, Sialkot, Punjab, Pakistan, to estimate the incidence of the three viruses of interest in potato cultivars 'Cardinal' and 'Desire'. Leaf samples (n=190) were collected randomly from 21 symptomatic and asymptomatic plants in nine fields, three fields from each location. Leaves were collected from the top, middle, and lower portions of plants and placed into plastic bags. Samples were stored on dry ice during transportation and stored at -80 °C freezer.

### 2.2. Serological detection

Potato leaf samples were tested for the presence of the three potato viruses of interest using a double-antibody sandwich enzyme-linked immune sorbent assay (DAS-ELISA) on a polystyrene microtiter plate, as previously described (Clark and Adam, 1977). The ELISA kit for PVX, PVY, and PLRV were purchased from Bioreba (Reinach, Switzerland). Leaf samples were ground in sample buffer provided and the assays were run, according to the manufacturer's instructions. Briefly, to detect virus in the sap preparations, the purified, respective virus-specific polyclonal antibodies were diluted 1000x in carbonate buffer (pH 9.6) and used to coat each well of the microtiter plate (200ul/well), with incubation for 24 hours at 4 °C. Following three washes with PBS-Tween, the diluted leaf sap was applied to each well (200ul/well), incubated for 24 hours at 4 °C, and washed three times with PBS-tween. A 200ul volume of the alkaline phosphatase-conjugated virus antibody was transferred to each well followed by incubation for 3 hours at 37 °C. After the final washes, plates were incubated with p-nitrophenyl phosphate substrate buffer for 30min at 25 °C in dark. The absorbance values were recorded using a spectrophotometer, at an optical density (O.D.) of 405nm. Mean OD<sub>405</sub> values of healthy samples and extraction buffers were averaged their standard deviation was calculated and multiplied by 3 (Clark and Adam, 1977). Values equal to, nearly equal to, and greater than the standard deviation were considered positive for virus presence. The

percent disease incidence was calculated based on a previously published, standard method (Abbas et al., 2012). Percent incidence was calculated as,

$$\text{Percentage of virus – positive samples} = \frac{\text{DAS-ELISA virus-positive potato samples}}{\text{total number samples}} \times 100 \quad (\text{Eq. 1})$$

### 2.3. Greenhouse inoculation experiment

Virus-free, presumed healthy potato plants were grown from tubers planted in pots containing sand, field soil, and leaf composite later infected at 35 days after planting. Test plants were either aphid-inoculated or mechanically inoculated against PVY and PLRV. Because PVX was not detected in potato plants in the field, the virus was not included in the greenhouse experiments. For aphid-inoculation experiments, symptomatic potato leaves were detached from 8-9 week old source plants (14-16 leaf stage). To maintain the turgidity in leaves for 2-3 hours, individual leaf petioles were inserted into 1.5ml plastic tubes containing water and sealed with paraffin (Shrestha et al., 2014). Non-viruliferous, apterous green peach aphids *Myzus persicae* (Sulzer) were collected from potato plants maintained in the National Agriculture Research Centre, Islamabad, Pakistan and starved for 2 hours. This aphid species was selected for the experiments because it is among the most efficient aphid vectors of the plant viruses of interest in Pakistan (Veerbek et al., 2010). Aphids were transferred to the underside of detached leaves from selected potato source plants and allowed a 2min acquisition-access period. Ten aphids per plant were transferred to the abaxial surface of upper leaves of each test plants using a fine bristle camel's hair brush, confined to plants by a mesh cage (3-cm diameter x 1.5cm depth). The aphids were allowed a 2 hours inoculation-access period (IAP) after which they were removed from the plants.

Mechanical inoculation was carried out by first macerating leaves from source plants with a sterilized pestle and mortar in 50mM potassium phosphate buffer (pH 7.0) at a ratio of 10%w/v tissue to buffer (1g tissue/10ml buffer). The potato leaves were inoculated by rubbing sap on carborundum powder-treated leaves. Inoculation experiment was repeated three times and plants were maintained in a greenhouse under controlled conditions, 25°C day and 21°C night temperature, 50-70% relative humidity, and 16-hour natural daylight. Plants were observed periodically for symptom development for 1-4 weeks post-inoculation.

### 2.4. Total RNA isolation

In RNA isolation procedure 100mg of ELISA confirmed leaf tissues were homogenized in 1ml Tri-Reagent. The mixture was transferred to a centrifuge tube and 200ul of chloroform was added and centrifuged at 12000rpm for 15min. The aqueous phase was transferred to a fresh microfuge tube with 500ul isopropanol. The RNA pellets were obtained after centrifugation at 12000rpm. The supernatant was discarded, and the pellet was washed three times with 70% ethanol by gently inverting the tubes. The air-dried RNA pellet was dissolved in diethyl pyrocarbonate (DPEC) treated water.

### 2.5. Reverse transcriptase-polymerase chain reaction

The cDNA was synthesized from total RNA by using 10pmol of PVY and PLRV-specific reverse primers with reverse transcriptase and incubated at 45°C for 60min. The reaction was terminated by incubation at 70°C for 5min. The PCR reaction was run in a total volume of 25ul containing 16.25ul of double-distilled water, 2.5ul of 10x PCR buffer, 2ul dNTPs, 1ul each primer ((PLRV-CPF ATGAGTACGGTCGTGGTTAA, PLRV-CPR CTATTTGGGGTTTTGCAAAG) (PVY-CPF ACGTCCAAAATGAGAATGCC, PVY-CPR TGGTGTTCGTGATGTGACCT)), 2ul of cDNA, and 0.25ul Taq enzyme. The cycling parameters for PVY were for an initial denaturation of 94°C for 3min followed by 35 cycles of 94°C for the 30sec, 51°C for 30sec, 72°C for 30sec, with a final extension at 72°C for 5min. The PLRV cDNA PCR amplification parameters were for one cycle of 94°C for 3min, followed by 35 cycles of 94°C for 45sec, 58°C for 45sec, 72°C for 45sec, with a final extension at 72°C for 5min. PCR amplified product was visualized on a 1% agarose gel stained with ethidium bromide. A 1kbp molecular marker (Waltham, Massachusetts, United States) was co-electrophoresed with amplicons as a size (mass) reference. The amplicons were eluted from gel using the Gene JET gel extraction kit (Waltham, Massachusetts, United States).



## 2.6. DNA sequencing and phylogenetic analysis

Following the successful amplification of target region of the genome. The amplified products were prepared and outsourced to macrogen Korea to obtain DNA sequencing. The obtained raw sequencing data were subsequently utilized for phylogenetic analysis. To infer the evolutionary relationship among the sequences, phylogenetic analysis was conducted using the Clustal W version. The clustal W algorithms aligns multiple sequencing. The aligned sequences were used to construct a phylogenetic tree. Providing insights into the genetic relatedness and evolutionary divergence of the studied DNA fragments.

## 3. Results and Discussion

In this study 190 symptomatic and non-symptomatic potato leaves were collected from nine potato fields located in Sialkot, Punjab Province and subjected to ELISA to detect the presence of PLRV, PVY, and PVX. Virus-specific PVX, PVY, and PLRV antisera were used for virus detection by DAS-ELISA. Based on ELISA results for the 190 samples tested, PVY and PLRV were detected in all of the areas surveyed in this study. The most prevalent virus was PVY, with an incidence of 63.15% in both cultivars, followed by PLRV at 45.83%, respectively. Also, mixed infections of PVY with PLRV were detected at a frequency of 8.3%. However, PVX was not detected in any potato plants among all of the locations sampled. Of the 190 samples tested, 16% were negative for all three viruses (*Figure 1*). Potato plant samples identified as positive for PLRV by ELISA testing exhibited upward rolling of leaf margins, foliar mottling, and stunting of plants. Potato plants found to be infected with PVY developed symptoms consisting of foliar mosaic, necrosis, and vein-clearing, stunting of plants, and reduced tuber size. Plants found to be co-infected with PVY and PLRV exhibited interveinal chlorosis, overall reduced size of the plant, and prominent upward leaf rolling. In some of the latter field-infected plants symptoms were extremely severe, and consisted of overall stunting, leaf distortion, and necrotic blotches.



**Figure. 1** A survey of potato fields to assess the incidence of PLRV, PVX, and PVY in the district Sialkot

Inoculation of virus-free or otherwise ‘healthy controls’, the potato plants maintained, in greenhouse developed symptoms reminiscent of field-collected plants found to be infected with PVY or PLRV by ELISA testing. The symptoms on test plants developed ten days post-inoculation and were indistinguishable from those observed in the field-infected potato plants reported previously in Pakistan (Abbas et al., 2014) and Turkey (Yardımcı et al., 2015). In greenhouse experiments, virus infection of aphid-and sap-inoculated test plants were verified by RT-PCR and confirmatory DNA sequencing of cloned amplicons (Genbank Accession no. OK188143 and OK188144).

Yield loss was estimated by counting the number of tubers in ‘healthy controls’ and virus infected potato plants (Rahman et al., 2010). In this study results showed that among three potato viruses studied here, PVY was the predominant virus infecting potato, at 63.15%, with PLRV being the second most prevalent, at 45.83%. High incidence of PVY and PLRV indicated that the environmental conditions were conducive to disease development, transmission, and susceptible cultivars, and use of virus-infected seed tubers.

Accurate detection of plant viruses is essential for selecting disease-free seed tubers for commercial planting. The coat protein gene is the most conserve and reliable region for virus detection for most plant viruses. In this study, PLRV-specific primers from coat protein gene amplified 627bp fragments, while the PVY-specific primers from coat protein gene amplified 790bp fragments by RT-PCR, with no non-specific amplification in any sample. The BLAST analyses indicated that the amplicons shared 99% and 99.8% similarity to PVY and PLRV, respectively. The PVY isolate shared it's best match (highest similarity score, coverage, and e-value) with the isolates from China (HM036202.1) and Kashmir (KY851109.1), at 99%, while PLRV was most closely related to isolates MF276872.1 and KR051180.1 reported previously from Sahiwal, Pakistan, and China, with a 99.8% similarity score. The isolates identified from the mixed infections of potato were most closely related to PVY (MW881192) and PLRV (MW881193) isolates from the United Kingdom and China.

Knowledge of phylogenic relationships among viral species and strains is useful for understanding differences in prevalence and distribution among geographical isolates and trace the source in plant materials derived by vegetative propagation (Mattews, 2002; Gibbs and Ohshima, 2010). To determine the relationships between Sialkot isolates of Pakistan and other isolates in NCBI database of respective viruses, the viral coat protein sequences were aligned using the ClustalW method (Thompson et al., 1994) and phylogenetic analysis was carried out according to Kumar et al. (2016). The phylogeny (neighbor-joining) phylogenetic tree grouped the Pakistan potato PLRV isolates with PLRV isolates reported from Heilongjiang, China and Pakistan (Accession no. KR051180.1 and MF276872.1), respectively (*Figure 2*), and one PVY isolate was most closely related to an isolate from Xinjiang, China (HM036202.1), while a second PVY isolate was most closely related to a PVY isolate from the United Kingdom (EU161658.1) (*Figure 3*).

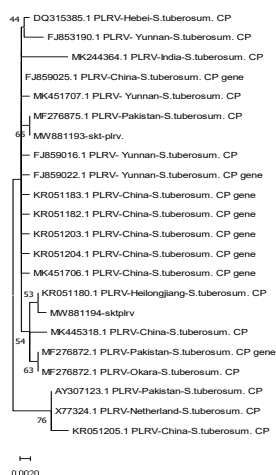


**Figure 2. Phylogenetic analysis of Potato leafroll virus detected from Sialkot district of Pakistan using nucleotide sequences from different isolates from NCBI. The phylogenetic tree was constructed using MEGA7 using the neighbor-joining method**

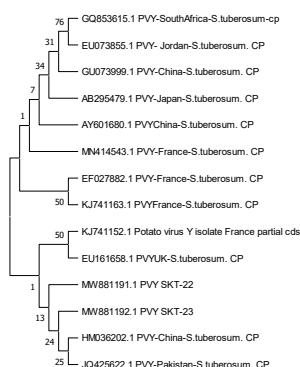


**Figure 3. Phylogenetic analysis of Potato virus Y detected from Sialkot district of Pakistan using nucleotide sequences from different isolates from NCBI. The phylogenetic tree was constructed using MEGA7 using the neighbor-joining method**

Previous studies in Pakistan have shown that PVY, PVS and PVX were most prevalent in the Punjab province of Pakistan (Hameed et al., 2014). However, in this study, PVX was not detected in any of the commercially grown potato fields in Pasrur, Sambrial and Daska, Sialkot in the Punjab province. This result suggests that dominance of a particular virus has changed over the time. The possible reason for this could be resistant cultivar of potato against PVX and disease management. However, PVY and PLRV were major pathogens threatening potato production worldwide (Ali et al., 2019). Based on this study, PVY and PLRV were the two most prevalent viruses infecting potato crops in Sialkot within this sampling time frame, with both viruses detected in cv. ‘Cardinal’ and cv. ‘Desire’ potato varieties. The observations from this study are consistent with previous reports that PVY and PLRV occur as single and mixed infections in most potato-growing regions of the world. Mixed virus infections in potato can result in substantial economic loss by reducing tuber size and quality compared to potato plants infected with only one virus infection (Wang et al., 2011). Results further underscore that management of potato-infecting RNA viruses is essential and relies on sensitive, accurate assays capable of detecting and identifying virus variants year-to-year to not only ensure that clean seed is available for planting, while also providing knowledge of possible shifts in viral strains or species. The production of virus free seed potato is therefore one of most important steps in reducing virus disease incidence in potato plantings, particularly early in the growing season, which can lead overall to consistently profitable, sustainable production of potato crops.

#### **4. Conclusions**

The results demonstrated the prevalence of individual virus and co-infection effects on two varieties ‘Cardinal’ and ‘Desire’. The results revealed that disease severity associated with the mixed infection were higher than value from individual virus infection. Monitoring the phytosanitary status of potato crops in Pakistan with highly sensitive technique such as RT-PCR must be a short-term target. Thus, diagnosis of potato-infecting RNA viruses at all stages of the certification process of potato seed-tubers is important to support a sustainable potato industry.

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#### **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

#### **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

#### **Authorship Contribution Statement**

Concept: Yasmin, S.; Design: Yasmin, S.; Data Collection or Processing: Yasmin, S.; Statistical Analyses: Yasmin, S.; Literature Search: Yasmin, S.; Writing, Yasmin, S.; Review and Editing: Yasmin, S.; and Kayim, M.

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**Tüketicilerin Coğrafi İşaretli Ürün Satın Alma Davranışları: Ezine Peyniri Örneği\***

Consumers' Purchasing Behaviors of Product with Geographical Indication: The Case of Ezine Cheese

Alptekin Mert YILMAZ<sup>1\*</sup>, Özge Can NİYAZ ALTINOK<sup>2</sup>, Oktay TOMAR<sup>3</sup>

**Öz**

Coğrafi işaret, tüketiciler için ürünün kaynağını, karakteristik özelliklerini ve ürünün söz konusu karakteristik özellikleri ile coğrafi alan arasındaki bağlantıyı gösteren ve garanti eden kalite işaretidir. Bu araştırmanın amacı Türkiye'deki tüketicilerin coğrafi işaretli ürün satın alma davranışı üzerinde etkili faktörleri belirlemektir. Araştırmanın ana materyalini İstanbul, Ankara ve İzmir'de yaşayan 394 tüketici ile yapılan anketlerden elde edilen veriler oluşturmaktadır. Verilerin analizinde tanımlayıcı istatistikler, faktör analizi ve lojistik regresyon analizinden yararlanılmıştır. Araştırma bulgularına göre, tüketicilerin %75.9'unun Ezine peyniri satın aldığı ve %61.5'inin Ezine inek peyniri tercih ettiği tespit edilmiştir. Faktör analizi sonucunda kırsal kalkınma, tat ve memnuniyet, kalite, gıda güvenliği, ürünü tanıma, fiyat ve ürünü konumlandırma faktörü olmak üzere 7 faktör bulunmuştur. Lojistik regresyon analizi sonuçlarına göre tüketicilerin Ezine peyniri satın alma durumu üzerinde tat ve memnuniyet faktörü, ürünü tanıma faktörü, ürünü konumlandırma (ayrı tutma) faktörü, cinsiyet, medeni durum ve aylık kişisel gelir bağımsız değişkenlerinin etkili olduğu tespit edilmiştir. Bu sonuçlar değerlendirildiğinde coğrafi işaretli ürünlerin tanıtımı ve pazarlama stratejileri geliştirilirken, ürünlerin coğrafi kökeni ve kalitesi özellikle vurgulanmalıdır. Üreticiler, ürünlerinin lezzetini korumak ve müşteri memnuniyetini artırmak için sürekli olarak ürün kalitesini ve lezzetini iyileştirmeli ve bu noktayı vurgulamalıdır. Ürün fiyatlandırması yaparken, coğrafi işaretli ürünlerin değeri ve kalitesi ile uyumlu bir fiyat stratejisi belirlemek gerekmektedir. Tüketiciler arasında coğrafi işaretli ürünlerin faydaları hakkında daha fazla bilinç yaratılmalıdır. Ürünlerin coğrafi kökeninin, üretim yöntemlerinin ve kalite standartlarının tüketicilere daha iyi anlatılması gerekmektedir. Coğrafi işaretli ürünlerin üretimi için kırsal alanlarda tarım ve hayvancılığı destekleyen politikaların uygulanması ve bu bölgelerin ekonomik kalkınmasına katkı sağlanması önemlidir. Cinsiyet, medeni durum ve aylık kişisel gelir gibi demografik faktörler tüketicilerin coğrafi işaretli ürün satın alma davranışını etkilediğinden ürün pazarlama stratejileri bu faktörleri de dikkate alarak geliştirilmelidir.

**Anahtar Kelimeler:** Coğrafi işaret, Tüketici, Türkiye, Faktör analizi, Lojistik regresyon

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## **Abstract**

A geographical indication is a quality sign that indicates and guarantees consumers the source of the product, its characteristic features, and the connection between the product's characteristics and the geographical area. This research aims to determine the factors affecting the purchasing behavior of consumers in Türkiye for geographically indicated products. The primary dataset for this research comprises survey data collected from 394 consumers living in Istanbul, Ankara, and Izmir. Descriptive statistics, factor analysis, and logistic regression were employed for data analysis. The research findings revealed that 75.9% of consumers purchased Ezine cheese, with 61.5% preferring Ezine cow cheese. Factor analysis identified seven key factors influencing purchasing behavior: rural development, taste and satisfaction, quality, food safety, product recognition, price, and product positioning. The results of logistic regression analysis indicated that the independent variables of taste and satisfaction, product recognition, product positioning (separation), gender, marital status, and monthly personal income significantly influenced consumers' decisions to purchase Ezine cheese. In light of these findings, promoting and marketing strategies for geographically indicated products should prioritize highlighting the geographical origin and product quality. Manufacturers should continually improve product quality and taste to enhance customer satisfaction. Pricing strategies should align with the value and quality of geographically indicated products. Increased consumer awareness about the benefits of these products is crucial, emphasizing the importance of explaining their geographical origin, production methods, and quality standards. Supportive policies for agriculture and animal husbandry in rural areas are essential to boost the production of geographically indicated products and contribute to the economic development of these regions. Additionally, demographic factors such as gender, marital status, and monthly personal income should be considered in the development of product marketing strategies.

**Keywords:** Geographical indication, Consumer, Türkiye, Factor analysis, Logistic regression



## 1. Giriş

Gıda sektöründe yaşanan taklit ve tağşişler, gıda güvenliğine yönelik endişeler ve salgın hastalıklar gibi birçok sebep tüketicilerin sağlıklı, güvenilir, çevre dostu ve üretim yeri bilinen gıdalara yönelmesine yol açmıştır (Brewer ve ark., 1994; Liu ve Niyongira, 2017). Tüketiciler tarafından tarımsal ürünlerin kaynağı ve üretim yöntemleri giderek daha fazla önemsenmektedir (Özdemir ve ark., 2017). Ürünlerin menşei, üretim aşamalarını ve karakteristik özelliklerini belirtmek amacıyla ürün etiketlemelerinden yararlanılmaktadır (Jansen ve Lince de Faria, 2002; Boström ve Klintman, 2008). Coğrafi işaretler de ürün etiketleme yöntemleri arasında yer almaktadır. (Menapace ve Moschini, 2011). Coğrafi işaret, “belirgin bir niteliği, ünü veya diğer özellikleri bakımından kökenin bulunduğu yöre, alan, bölge veya ülke ile özdeşleşmiş ürünü gösteren işaret” olarak tanımlanmaktadır (TÜRKPATENT, 2023). Coğrafi işaretler sayesinde geleneksel üretim yöntemleri ve yerel halkın bilgi ve becerilerinin yansıtıldığı ürünlerin tanıtılması ve korunması sağlanmaktadır. Bu nedenle, coğrafi işaretler hem üreticiler için ekonomik avantajlar sunmakta hem de tüketicilere kalite, özgünlük ve köken güvencesi sağlamaktadır (Menapace ve ark., 2008). Tüketicilerin gıda güvenliğine ilişkin endişelerinin artış göstermesi coğrafi işaret tescilinin de içinde yer aldığı kalite güvencesine dair kavramlara olan ihtiyacın artmasına yol açmaktadır (Menapace ve ark., 2009). Dolayısıyla coğrafi işaretlerin dünya genelinde ticari etiketleme ve koruma sistemi olarak kullanımı artmaktadır. Coğrafi işaretler sadece gıda ürünleri için değil, aynı zamanda el sanatları ve tekstil ürünleri gibi gıda dışı alanlarda da kullanılmaktadır. Fakat gıda dışı ürünlerle kıyaslandığında tarım ve gıda ürünlerinde coğrafi işaret tescili daha yaygındır (Menapace, 2010).

Coğrafi işaretler menşe adı ve mahreç işareti olarak ikiye ayrılmaktadır. Mahreç işaretli ürünlerde ürünün üretim aşamalarından en az birinin ilgili bölgede gerçekleştirilmesi yeterliyken, menşe adına sahip ürünlerde ürünün tüm üretim aşamalarının ilgili bölgede gerçekleştirilmesi şarttır (Teuber, 2011). Menşe adına Lapseki şeftalisi, İzmit pişmaniyesi; mahreç işaretine ise Adana kebabı, İzmit simidi ve Afyon sucuğu örnek verilebilmektedir. Coğrafi işaretin ürün, belirli bir coğrafya, ürünün ayırt edici özelliğe sahip olması, işaret, ürünün ayırt edici özellikleri ve coğrafya arasında bağlantı olması olmak üzere 5 unsuru bulunmaktadır (Coşkun, 2001; Gündoğdu, 2006; Tuncay, 2009). Coğrafi işaretin işlevleri birincil (asli) ve ikincil (tali) olmak üzere iki kategoriye ayrılmaktadır. Buna göre coğrafi işaretin birincil işlevleri arasında ayırt etmek, ürünün üretim metodunu ve kalitesini garanti etmek, coğrafi kaynak belirtmek ile pazarlama aracı olmak bulunmaktadır. Coğrafi işaretin ikincil işlevleri arasında ise yerel üretimi ve kırsal kalkınmayı desteklemek, turizme katkıda bulunmak, geleneksel bilgi ve kültürel değerleri korumak, çevreyi ve biyolojik çeşitliliği korumak ile ürün taklitçiliğiyle mücadele etmek yer almaktadır (Gündoğdu, 2006; Tepe, 2008).

Avrupa Birliği’nde (AB) geleneksel ürün adına sahip ve coğrafi işaretli ürünlerin toplam ekonomik değeri 77 milyar Euro’dur (EC, 2021). Bunun yanı sıra sertifikasız ürünlerle kıyaslandığında coğrafi işaretli ürünler ortalama olarak iki kat daha fazla satış değerine sahiptir (EC, 2020). Dolayısıyla AB ekonomisinde büyük öneme sahip olan coğrafi işaret tescilli ürünlerin Türkiye’de de yaygınlaştırılması gerekmektedir.

Türkiye’de coğrafi işaretli ürünler ile ilgili tüketici profilinin il bazında ortaya konulduğu birçok çalışmaya rastlamak mümkündür. Bu çalışmaların yapıldığı iller arasında Karaman (Kan ve ark., 2010), İstanbul (Zuluğ, 2010), Kahramanmaraş (Meral, 2013; Aytıp ve Şahin, 2014), Siirt (Oğuz, 2016), Artvin (Toklu, 2016), Doğu Karadeniz Bölgesi (Toklu ve ark., 2016), Erzurum, Erzincan ve Bayburt’u içeren TRA1 Bölgesi (Topçu ve Yalçın, 2016), Antalya (Çakaloğlu ve Çağatay, 2017), Erzurum (Baran ve Topçu, 2018; Güler, 2019), Kastamonu (Duman, 2018; Keskin ve ark., 2019), Gaziantep (Küçükyılmaz, 2019), Ankara (Sancak, 2019), Tokat (Topbaş, 2019), Samsun (Yılmaz, 2020) ve Gümüşhane (Doğan ve Adanacıoğlu, 2022) yer almaktadır. Fakat coğrafi işaretli ürünlere ilişkin İstanbul, Ankara ve İzmir genelini kapsayan tüketici davranışı çalışmasına rastlanmamıştır. Coğrafi işaretli ürünlere ilişkin İstanbul, Ankara ve İzmir genelini kapsayan çalışmanın yapılmaması bu çalışmanın önemini artırmaktadır.

Son yıllarda tüketicilerin eğitim ve gelir seviyesindeki artış ile yaşam tarzlarındaki değişiklikler tüketici davranışlarının değişmesine yol açmıştır. Tüketici davranışlarındaki bu değişiklikler tüketicilerin satın alma davranışlarını etkileyen faktörlerin belirlenmesinin önemini ortaya koymaktadır (Ağır ve Akbay, 2021). Bu çalışmanın amacı Türkiye’deki tüketicilerin coğrafi işaretli ürün satın alma davranışlarının belirlenmesidir. Bu açıdan bu çalışmanın sonuçlarının coğrafi işaret konusunda çalışan karar vericilere önemli katkı sağlaması ve üretici ve tüketicilerin duyarlılığını artırması beklenmektedir. Ürünlerin haksız rekabetten korunmasında büyük

öneme sahip olan coğrafi işaretler sayesinde tescil yapılmadığı durumda yaşanacak ekonomik kayıplar azaltılabilecektir.

## 2. Materyal ve Metot

Araştırmanın ana materyalini 2021 yılında İstanbul, Ankara ve İzmir'deki tüketicilerle çevrimiçi yapılan anketlerden elde edilen veriler oluşturmaktadır. Çalışmanın ikincil verilerini ise konu ile ilgili ulusal ve uluslararası kaynaklar oluşturmaktadır. Anket yapılacak kişi sayısı Olasılıklı Örneklem Yöntemi ile tespit edilmiş (Newbold ve ark., 1995) ve %95 güven aralığı %5 hata payı ile örnek hacmi 383 olarak hedeflenmiştir. Uygulanması planlanan anket sayısı deneklerin araştırmaya olan ilgisine göre artırılabilir. Çalışmanın anket aşaması katılımcıların istekliliğinin yüksek olması sebebiyle hedeflenen 383 anket sayısı aşılarak 394 tüketicinin katılımıyla sonuçlandırılmıştır.

$$n = \frac{N.t^2.p.q}{d^2.(N-1)+t^2.p.q} \quad (\text{Eş. 1})$$

Formülde n: Örneklem alınacak tüketici sayısını, N: Hedef kitledeki tüketici sayısını, t:Belirli bir anlamlılık düzeyinde t tablosuna göre bulunan teorik değeri, p:İncelenen olayın gerçekleşme olasılığını (Coğrafi İşaretli Ürün Satın Alma Durumu), q: İncelenen olayın gerçekleşmeme olasılığını (Coğrafi İşaretli Ürün Satın Almama Durumu), d:Olayın görülüş sıklığına göre kabul edilen  $\pm$  örneklem hatasını ifade etmektedir. Literatürde, eğer aynı konuda daha önce bir çalışma yapılmadıysa, örneklem hacmini en yüksek seviyeye çıkarmak amacıyla p ve q değerleri genellikle 0.5 olarak alınmaktadır (Aytop, 2019; Aytop ve Fikret, 2020; Everest ve ark., 2022). Bu nedenle çalışmada en yüksek örneklem hacmine ulaşmak için p = 0.5 ve q = 0.5 alınmıştır.

Araştırma kapsamında yapılan anketlerin illere göre dağılımı *Tablo 1*'de verilmiştir. Buna göre İstanbul'dan 239, Ankara'dan 87 ve İzmir'den 68 tüketicinin katılımı ile 07.10.2021 – 17.12.2021 tarihleri arasında anket tamamlanmıştır.

**Tablo 1. Araştırma kapsamında yapılan anketlerin illere göre dağılımı**

*Table 1. Distribution of surveys conducted within the scope of the research by province*

| 2021 TÜİK Verileri    | Nüfus (Kişi) | Türkiye İçinde Oran (%) | 3 il İçinde Oran (%) | Anket Dağılımı |
|-----------------------|--------------|-------------------------|----------------------|----------------|
| İstanbul Nüfus        | 15.462.452   | 18.2                    | 60.6                 | 239            |
| Ankara Nüfus          | 5.663.322    | 6.7                     | 22.2                 | 87             |
| İzmir Nüfus           | 4.394.694    | 5.2                     | 17.2                 | 68             |
| Üç İlin Toplam Nüfusu | 25.520.468   | 30.1                    | 100.0                |                |
| Türkiye Nüfusu        | 84.680.273   | 100.0                   |                      | 394            |

Araştırma verilerinin analizinde tanımlayıcı istatistikler, faktör analizi ve lojistik regresyon analizinden yararlanılmıştır. Likert tipi sorularda; 5= Kesinlikle Katılıyorum, 4= Katılıyorum, 3= Ne katılıyorum ne de katılmıyorum, 2= Katılmıyorum, 1= Kesinlikle Katılmıyorum'u ifade etmektedir. Ayrıca 5'li Likert ölçekli yargıların değerlendirilmesinde Likert Ölçek Ortalaması kullanılmıştır (Likert, 1932; Boone ve Boone, 2012; Sullivan ve Artino, 2013; Harpe, 2015; Subedi, 2016; Joshi ve ark., 2015).

Faktör analizi, birbiriyle ilişkili değişkenlerin yer aldığı veri setini daha az sayıda ve birbirinden bağımsız olacak şekilde yeni değişkenlerden oluşan bir veri setine çevirmek, oluşturulan bu yeni veri setindeki değişkenleri gruplandırmak suretiyle bir olay veya durumu açıkladıkları öngörülen ortak olan faktörleri belirlemek, bu oluşumu etkileyen faktörlerden minör ve majör olanları belirlemek amacıyla kullanılan bir analiz yöntemidir (Spearman, 1904; Cooper, 1983; Ford ve ark., 1986; Fabrigar ve ark., 1999; Özdamar, 2013; Yong ve Pearce, 2013; Kline, 2014). Bu çalışmada faktör analizi tüketicilerin Ezine peyniri satın alma davranışı üzerinde etkili olması beklenen yargıların benzer boyutlar altında toplanması amacıyla kullanılmıştır. Faktör analizi sonrası 5'li Likert ölçekli yargılar daha az sayıya indirgenen değişken grupları (faktörler) altında gruplandırılarak adlandırılmıştır. Faktör analizinden elde edilen faktörler daha sonra ikili lojistik analizinde bağımsız değişken olarak kullanılmıştır. Faktör analizi sonucunda oluşan skorları regresyon analizinde kullanmanın çoklu bağlantı gibi bazı sorunların ortadan kaldırılmasında ve oluşan bu skorların en yüksek verimlilikte kullanılabilmesine yönelik çalışmalar mevcuttur (Scott, 1966; Grice, 2001; Skrondal ve Laake, 2001; DiStefano ve ark., 2009). Bu çalışmada da faktör analizi sonucunda elde edilen skarlardan ikili lojistik

regresyon analizinde yararlanılmıştır. Faktör analizi, birçok Likert ölçekli değişkeni, altında yatan daha az sayıda faktöre indirgemek için kullanılmaktadır. Bu işlem sonucunda elde edilen faktör skorları, bu faktörlerin gözlemlenen değişkenler üzerindeki etkisini yansıtan sürekli değerlerdir. Bu skorlar, faktörlerin ağırlıklandırılmış ortalamaları olarak düşünülebilir ve sürekli bir ölçek üzerinde konumlanmaktadır. Faktör skorları, sürekli bir ölçekte yer aldıkları ve teorik olarak sonsuz sayıda değer alabilecekleri için sürekli değişken olarak kabul edilmektedir. Bu nedenle, regresyon analizinde faktör skorları kullanıldığında, bağımsız veya bağımlı değişkenler olarak sürekli değişkenler olarak ele alınmaktadır. Sonuç olarak, regresyon analizinde, 5'li Likert ölçekli yargılardan faktör analizi yoluyla elde edilen faktör skorları genellikle sürekli değişken olarak kabul edilmektedir (Skrondal ve Laake, 2001; Hayes ve Usami, 2020).

Lojistik regresyon ile bağımlı ve bağımsız değişkenler arasındaki ilişki incelenmektedir (Berkson, 1944; Kleinbaum ve ark., 2002; Peng ve ark., 2002; Hosmer Jr. ve ark., 2013; Sperandei, 2014; Harrell, 2015; Tranmer ve ark., 2023). Birçok bilim alanında kullanılan lojistik regresyon analizi, tarım ekonomisi alanında da sıklıkla kullanılan analizler arasındadır. Lojistik regresyon analizi binary, nominal ve ordinal olmak üzere üç şekilde uygulanmaktadır. Binary (İkili) lojistik regresyon analizi evet ve hayır gibi iki cevap seçeneği bulunan bağımlı değişkenlerde uygulanan regresyon analizidir. Bu çalışmada binary (ikili) lojistik regresyon modelinde bulunan bağımlı değişken Ezine peyniri satın almama durumu=1 (hayır), Ezine peyniri satın alma durumu=2 (evet) olarak kodlanmıştır. Buna göre modelde yer alan tüm değişkenler ve bu değişkenlerin özellikleri *Tablo 2*'de verilmiştir.

**Tablo 2. Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma durumu üzerinde etkili olan değişkenlere yönelik yapılan lojistik regresyon analizinde kullanılan değişkenler ve özellikleri**

*Table 2. Variables and their characteristics used in the logistic regression analysis for the variables affecting the Ezine cheese purchasing status of the consumers within the scope of the research*

| Değişkenlerin İsimleri                   | Değişkenlere Ait Gruplar ve Özellikleri                                                                                                                                                               |
|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Bağımlı Değişken</b>                  |                                                                                                                                                                                                       |
| Ezine Peyniri Satın Alma Durumu          | Sözde (Nominal) Ölçek: 1=Hayır, 2=Evet                                                                                                                                                                |
| <b>Bağımsız Değişkenler</b>              |                                                                                                                                                                                                       |
| Kırsal Kalkınma Faktörü                  | Aralıklı (Scale) Ölçek                                                                                                                                                                                |
| Tat ve Memnuniyet Faktörü                | Aralıklı (Scale) Ölçek                                                                                                                                                                                |
| Kalite Faktörü                           | Aralıklı (Scale) Ölçek                                                                                                                                                                                |
| Gıda Güvenliği Faktörü                   | Aralıklı (Scale) Ölçek                                                                                                                                                                                |
| Ürünü Tanıma Faktörü                     | Aralıklı (Scale) Ölçek                                                                                                                                                                                |
| Fiyat Faktörü                            | Aralıklı (Scale) Ölçek                                                                                                                                                                                |
| Ürünü Konumlandırma (Ayrı Tutma) Faktörü | Aralıklı (Scale) Ölçek                                                                                                                                                                                |
| Yaş                                      | Aralıklı (Scale) Ölçek                                                                                                                                                                                |
| Cinsiyet                                 | Sözde (Nominal) Ölçek: 1=Erkek, 2=Kadın                                                                                                                                                               |
| Medeni Durum                             | Sözde (Nominal) Ölçek: 1=Evli, 2=Bekar                                                                                                                                                                |
| Çocuk Sahibi Olma Durumu                 | Sözde (Nominal) Ölçek: 1=Evet, 2=Hayır                                                                                                                                                                |
| Hanede Yaşayan Kişi Sayısı               | Aralıklı (Scale) Ölçek: 1= 1 ile 3 kişi arası, 2= 4 kişi ve üzeri                                                                                                                                     |
| Aylık Kişisel Gelir                      | Aralıklı (Scale) Ölçek: 1=Gelirim yok, 2= 1.000 TL veya daha az, 3= 1.001-2.000 TL, 4= 2.001-3.000 TL, 5= 3.001-4.000 TL, 6= 4.001-5.000 TL, 7=5.001-6.000 TL, 8= 6.001-7.000 TL, 9=7.001 TL ve üzeri |
| Aylık Toplam Hane Geliri                 | Aralıklı (Scale) Ölçek: 1=2.500 TL veya daha az, 2= 2.501-5.000 TL, 3= 5.001-7.500 TL, 4= 7.501-10.000 TL, 5=10.001-12.500 TL, 6=12.501-15.000 TL, 7=15.001 TL ve üzeri                               |

### 3. Araştırma Sonuçları ve Tartışma

Araştırma kapsamındaki tüketicilere ait demografik özellikler *Tablo 3*'te verilmiştir. *Tablo 3* incelendiğinde tüketicilerin % 50.7'sinin 18-28 yaş arasında (ortalama yaş: 30,4 yıl), %58.6'sının kadın, % 64.5'inin bekar, %27.7'sinin memur olduğu tespit edilmiştir. Bunun yanı sıra tüketicilerin % 22.3'ünün hanehalkı ortalama

aylık gelirlerinin 5001-7500 TL arasında olduğu ve % 19.2'sinin aylık kişisel gelirinin 7001 TL ve üzeri olduğu belirlenmiştir. Tüketicilerin % 60.4'ünün 1-3 kişiden oluşan haneye (hanede yaşayan ortalama birey sayısı: 3) ve

**Tablo 3. Araştırma kapsamındaki tüketicilerin sosyo-demografik özellikleri**

*Table 3. Socio-demographic characteristics of consumers within the scope of the research*

| Demografik özellikler                    | Kişi sayısı | Oran (%) | Demografik özellikler           | Kişi sayısı | Oran (%) |
|------------------------------------------|-------------|----------|---------------------------------|-------------|----------|
| <b>Yaş (Yıl) (ortalama yaş: 30.4)</b>    |             |          | <b>Cinsiyet</b>                 |             |          |
| 18 ile 28 yaş arası                      | 200         | 50.7     | Kadın                           | 231         | 58.6     |
| 29 ile 38 yaş arası                      | 135         | 34.3     | Erkek                           | 163         | 41.4     |
| 39 ile 48 yaş arası                      | 42          | 10.7     | Toplam                          | 394         | 100      |
| 49 ile 58 yaş arası                      | 13          | 3.3      | <b>Medeni durum</b>             |             |          |
| 58 yaş üzeri                             | 4           | 1        | Bekar                           | 254         | 64.5     |
| Toplam                                   | 394         | 100      | Evli                            | 140         | 35.5     |
| <b>Eğitim seviyesi</b>                   |             |          | Toplam                          | 394         | 100      |
| İlköğretim Mezunu                        | 5           | 1.3      | <b>Meslek</b>                   |             |          |
| Lise Mezunu                              | 62          | 15.7     | Memur                           | 109         | 27.7     |
| Üniversite Mezunu                        | 139         | 35.3     | Öğrenci                         | 102         | 25.9     |
| Yüksek Lisans Mezunu                     | 156         | 39.6     | Özel Sektör Çalışanı            | 73          | 18.5     |
| Doktora Mezunu                           | 32          | 8.1      | Serbest Meslek                  | 39          | 9.9      |
| Toplam                                   | 394         | 100      | Çalışmıyor                      | 29          | 7.3      |
| <b>Hanehalkı büyüklüğü (ortalama: 3)</b> |             |          | Ev Hanımı                       | 15          | 3.8      |
| 1 ile 3 kişi arası                       | 238         | 60.4     | Esnaf                           | 11          | 2.8      |
| 4 kişi ve üzeri                          | 156         | 39.6     | İşçi                            | 11          | 2.8      |
| Toplam                                   | 394         | 100      | Emekli                          | 5           | 1.3      |
| <b>Aylık kişisel gelir</b>               |             |          | Toplam                          | 394         | 100      |
| Şahsi Geliri Yok                         | 88          | 22.3     | <b>Aylık toplam hane geliri</b> |             |          |
| 1.000 TL veya daha az                    | 22          | 5.6      | 2.500 TL veya daha az           | 8           | 2        |
| 1.001-2.000 TL                           | 24          | 6.1      | 2.501-5.000 TL                  | 66          | 16.8     |
| 2.001-3.000 TL                           | 26          | 6.6      | 5.001-7.500 TL                  | 88          | 22.3     |
| 3.001-4.000 TL                           | 34          | 8.6      | 7.501-10.000 TL                 | 72          | 18.3     |
| 4.001-5.000 TL                           | 40          | 10.2     | 10.001-12.500 TL                | 52          | 13.2     |
| 5.001-6.000 TL                           | 55          | 14       | 12.501-15.000 TL                | 41          | 10.4     |
| 6.001-7.000 TL                           | 29          | 7.4      | 15.001 TL ve üzeri              | 67          | 17       |
| 7.001 TL ve üzeri                        | 76          | 19.2     | Toplam                          | 394         | 100      |
| Toplam                                   | 394         | 100      |                                 |             |          |
| <b>Yaşanılan il</b>                      |             |          |                                 |             |          |
| İstanbul                                 | 239         | 60.7     |                                 |             |          |
| Ankara                                   | 87          | 22.1     |                                 |             |          |
| İzmir                                    | 68          | 17.2     |                                 |             |          |
| Toplam                                   | 394         | 100      |                                 |             |          |

%39.6'sının yüksek lisans mezunu olduğu ortaya konmuştur. Tüketicilerin % 60.7'sinin İstanbul'da yaşadığı ve % 62.7'sinin ise il merkezinde ikamet ettiği saptanmıştır. 2021 yılı itibariyle Türkiye nüfusunun % 93.2'sinin il ve ilçe merkezlerinde yaşadığı, % 6.8'inin ise köy ve beldelelerde yaşadığı tespit edilmiştir (TÜİK, 2022). Çevrimiçi anket yöntemi ile yapılan çalışmalarda eğitim seviyesi ve gelir seviyesi yüksek olan kişilerin internet kullanma olasılıkları daha yüksek olduğundan bu kişilerin çevrimiçi anketlere katılma ihtimalinin daha fazla olduğu tespit edilmiştir (Duda ve Nobile, 2010; Pew Internet, 2010; Graefe ve ark., 2011; Sexton ve ark., 2011; Vaske ve ark., 2011). Yapılan çalışmalarda çevrimiçi anket çalışmalarına katılanların daha yüksek eğitim ve gelir seviyesine sahip olduğu belirlenmiştir (Duda ve Nobile, 2010; Graefe ve ark., 2011; Sexton ve ark., 2011; Vaske ve ark., 2011). Küçükylmaz (2019) tarafından yapılan bir çalışmada lisans mezunlarının tüm katılımcılar içinde % 35.6'lık

paya sahip olduğu belirlenmiştir. Yılmaz (2020) tarafından yapılan bir çalışmada lisans mezunlarının oranının % 29.4 olduğu tespit edilmiştir. Sancak (2019) tarafından yapılan bir çalışmada araştırma kapsamındaki tüketicilerin %61'i üniversite mezunu, % 27'si yüksek lisans mezunu ve % 4'ü doktora mezunu olarak belirlenmiştir. 2021 yılı itibarıyla Türkiye nüfusunun ortalama yaşı 33.1 olarak saptanmıştır (TÜİK, 2022). Kırgız (2017) tarafından yapılan bir çalışmada araştırma kapsamındaki tüketicilerin % 4.8'inin 18 yaş altı, %38.5'inin 18-24 yaş arası, % 34.4'ünün 25-34 yaş arası, % 13.1'inin 35-44 yaş arası, % 7.9'unun 45-54 yaş arası, % 1.2'sinin 55-64 yaş arası ve % 0.2'sinin 65 yaş ve üzerinde olduğu belirlenmiştir. Zuluğ (2010) tarafından yapılan bir çalışmada araştırma kapsamındaki tüketicilerin % 32.2'sinin 20-29 yaş arasında, % 41.3'ünün 30-39 yaş arasında, %12.4'ünün 40-49 yaş arasında, % 11.6'sının 50-59 yaş arasında ve % 2.5'inin 60 yaş üzerinde olduğu tespit edilmiştir. 2021 yılı itibarıyla Türkiye nüfusunda kadınların oranı % 49.9, erkeklerin oranı ise % 50.1 olarak tespit edilmiştir (TÜİK, 2022). Gıda ürünlerine yönelik yapılmış tüketici davranışı çalışmalarında kadın katılımcıların çoğunlukta olduğu çalışmalara rastlamak mümkündür. Örneğin Yılmaz ve ark. (2009) tarafından yapılan bir çalışmada katılımcıların % 72.3'ünün kadın olduğu görülmektedir. Ayrıca coğrafi işaretli ürünlere yönelik yapılmış tüketici davranışı çalışmalarında da kadın katılımcıların daha fazla olduğu çalışmalara rastlamak mümkündür (Zuluğ, 2010). Yönet Eren (2018) tarafından yapılan bir çalışmada katılımcıların % 75.5'inin bekar, % 24.5'inin ise evli olduğu ortaya konmuştur. Kırgız (2017) tarafından yapılan bir çalışmada tüketicilerin % 70.4'ünün bekar, % 29.6'sının ise evli olduğu tespit edilmiştir. Meral ve Şahin (2013) tarafından yapılan bir çalışmada araştırma kapsamındaki tüketicilerin % 27.1'inin ev hanımı, % 16.4'ünün işçi, % 10.9'unun esnaf ve % 21.9'unun memur olduğu saptanmıştır. Kırgız (2017) tarafından yapılan bir çalışmada araştırma kapsamındaki tüketicilerin % 4.6'sının çalışmadığı, % 41.9'unun öğrenci olduğu, % 33.3'ünün özel sektörde çalıştığı, % 17.9'unun kamuda çalıştığı ve % 2.3'ünün emekli olduğu belirlenmiştir. Çakaloğlu ve Çağatay (2017) tarafından yapılan bir çalışmada araştırma kapsamındaki tüketicilerin % 22.5'inin kendi hesabına çalıştığı, % 66.0'ının ücretli ve yevmiyeli çalıştığı, % 10.0'ının çalışmadığı, % 1.5'inin bağımsız/sigortasız/geçici/parça başına çalıştığı tespit edilmiştir. 2021 yılı itibarıyla Türkiye'de ortalama hane büyüklüğü 3.2 olarak tespit edilmiştir (TÜİK, 2022). Zuluğ (2010) tarafından yapılan bir çalışmada araştırma kapsamındaki tüketicilerin % 30.6'sının hanesinde 3 kişi, %28.1'inin hanesinde 2 kişi ve % 22.3'ünün hanesinde 4 kişi yaşadığı belirlenmiştir. Fotopoulos ve Krystallis (2003) tarafından yapılan bir çalışmada daha üst sosyo ekonomik seviyede bulunan tüketicilerin coğrafi işaret tescilli Zagora elmasını daha fazla satın aldığı saptanmıştır. Küçükylmaz (2019) tarafından yapılan bir çalışmada araştırma kapsamındaki tüketicilerin % 52.7'sinin 2.100 TL ve altı, % 24.4'ünün 2.101 TL-3.500 TL arası, % 12.7'sinin 3.501-5.000 TL arası ve % 10.2'sinin 5.001 TL ve üzeri geliri olduğu tespit edilmiştir. Yılmaz (2020) tarafından yapılan bir çalışmada araştırma kapsamındaki tüketicilerin 26'sının 2.020 TL ve altında, 228'inin 2.021-5.000 TL arasında, 116'sının 5.001-10.000 TL arasında ve 14'ünün 10.000 TL ve üzerinde gelirinin olduğu belirlenmiştir.

Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma davranışlarına ilişkin bilgiler *Tablo 4*'te verilmiştir. *Tablo 4* incelendiğinde tüketicilerin % 75.9'unun Ezine peyniri satın aldığı, % 58.1'inin Ezine peynirinin coğrafi işaretli ürün olduğunu bilmediği, % 65.2'sinin Ezine peyniri ile diğer peynirlerin fiyatının aynı olması halinde coğrafi işaretli Ezine peynirini tercih ettiği, % 52.3'ünün Ezine peynirinin fiyatını pahalı bulduğu ve % 61.9'unun coğrafi işaretli bir ürüne daha fazla ödeme istekliliği bulunmadığı tespit edilmiştir. Bunun yanı sıra Ezine peyniri satın alan tüketicilerin (n=299) % 61.5'inin Ezine inek peyniri tercih ettiği, % 40.1'inin Ezine peynirini marketten satın aldığı, % 31.1'inin toplam peynir harcamasında Ezine peynirinin payının % 10 olduğu, % 53.8'inin Ezine peynirini ayda bir kez satın aldığı, % 34.8'inin Ezine peynirini haftada bir kez tükettiği belirlenmiştir. Ayrıca tüketicilerin (n=150) % 44'ünün coğrafi işaretli bir ürüne % 5-10 daha fazla ödeme istekliliğine sahip olduğu saptanmıştır. Meral ve Şahin (2013) tarafından yapılan bir çalışmada tüketicilerin % 37.6'sının zeytin alışverişini marketten yaptığı, % 35.6'sının direkt üreticiden, % 19.4'ünün süpermarketten, % 4.5'inin semt pazarından alıp kendisinin yaptığı, % 1.8'inin bakkaldan, % 0.9'unun semt pazarından hazır aldığı, % 0.3'ünün hipermarketten aldığı tespit edilmiştir. Fotopoulos ve Krystallis (2003) tarafından yapılan bir çalışmada tüketicilerin % 60.5'inin coğrafi işaretli elmaları açık pazarlardan, % 25.8'inin manavdan, % 11.7'sinin süpermarketten, % 0.9'unun direkt üreticiden, % 1.2'sinin diğer yerlerden satın aldığı ortaya konmuştur. Küçükylmaz (2019) tarafından yapılan bir çalışmada tüketicilerin % 24.4'ünün coğrafi işaretli Antep baklavasını yılda birkaç kez, % 12.2'sinin 6 ayda birkaç kez, % 25.2'sinin 3 ayda birkaç kez ve % 26.5'inin ayda birkaç kez tükettiği tespit edilmiştir. Ayrıca Küçükylmaz (2019) tarafından tüketicilerin % 68.2'sinin Antep baklavasının coğrafi işaretli olduğunu bildiği, % 31.8'inin ise bilmediği belirlenmiştir. Meral (2013) tarafından yapılan bir



çalışmada tüketicilerin % 94.8'inin Maraş dondurmasının coğrafi işaretli olduğunu bildiği, % 5.2'sinin ise bilmediği saptanmıştır. Meral (2013) tarafından yapılan bir çalışmada coğrafi işarete sahip Gemlik zeytini ve diğer zeytinlerin fiyatının aynı olması halinde tüketicilerin % 90.4'lük kısmının coğrafi işaret tescilli Gemlik zeytinini

**Tablo 4. Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma davranışları**

*Table 4. Ezine cheese purchasing behavior of consumers within the scope of the research*

| <b>Ezine Peyniri Satın Alma Davranışları</b>                                                         | <b>Kişi sayısı</b> | <b>Oran (%)</b> | <b>Ezine Peyniri Satın Alma Davranışları</b>                         | <b>Kişi sayısı</b> | <b>Oran (%)</b> |
|------------------------------------------------------------------------------------------------------|--------------------|-----------------|----------------------------------------------------------------------|--------------------|-----------------|
| <b>Ezine peyniri satın alma durumu</b>                                                               |                    |                 | <b>Tercih edilen Ezine peyniri türü</b>                              |                    |                 |
| Evet                                                                                                 | 299                | 75.9            | Ezine inek peyniri                                                   | 184                | 61.5            |
| Hayır                                                                                                | 95                 | 24.1            | Ezine keçi peyniri                                                   | 71                 | 23.7            |
| Toplam                                                                                               | 394                | 100             | Ezine koyun peyniri                                                  | 44                 | 14.7            |
| <b>Ezine peyniri satın alınan yer</b>                                                                |                    |                 | Toplam                                                               | 299                | 100             |
| Market                                                                                               | 120                | 40.1            | <b>Ezine peyniri satın alma sıklığı</b>                              |                    |                 |
| Süpermarket                                                                                          | 90                 | 30.1            | Ayda bir kez                                                         | 161                | 53.8            |
| Şarküteri                                                                                            | 65                 | 21.7            | Üç ayda bir kez                                                      | 92                 | 30.8            |
| Pazarlardan                                                                                          | 12                 | 4               | Haftada bir kez                                                      | 46                 | 15.4            |
| Doğrudan Üretici                                                                                     | 11                 | 3.7             | Toplam                                                               | 299                | 100             |
| Bakkal                                                                                               | 1                  | 0.3             | <b>Ezine peyniri tüketme sıklığı</b>                                 |                    |                 |
| Toplam                                                                                               | 299                | 100             | Haftada bir kez                                                      | 104                | 34.8            |
| <b>Toplam peynir harcamasında Ezine peynirinin payı</b>                                              |                    |                 | Her gün                                                              | 93                 | 31.1            |
| 10%                                                                                                  | 93                 | 31.1            | Üç ayda bir kez                                                      | 63                 | 21.1            |
| 20%                                                                                                  | 56                 | 18.7            | Ayda bir kez                                                         | 39                 | 13              |
| 30%                                                                                                  | 50                 | 16.7            | Toplam                                                               | 299                | 100             |
| 50%                                                                                                  | 53                 | 17.7            | <b>Ezine peynirinin coğrafi işaretli ürün olduğunu bilme durumu</b>  |                    |                 |
| 100%                                                                                                 | 10                 | 3.3             | Hayır                                                                | 229                | 58.1            |
| Bilmiyorum                                                                                           | 37                 | 12.4            | Evet                                                                 | 165                | 41.9            |
| Toplam                                                                                               | 299                | 100             | Toplam                                                               | 394                | 100             |
| <b>Ezine peyniri ile diğer peynirlerin fiyatının aynı olması durumunda tercih edilen peynir türü</b> |                    |                 | <b>Coğrafi işaretli bir ürüne ödeme istekliliği</b>                  |                    |                 |
| Coğrafi işaretli Ezine peyniri                                                                       | 257                | 65.2            | Hayır                                                                | 244                | 61.9            |
| Fark etmez                                                                                           | 102                | 25.9            | Evet                                                                 | 150                | 38.1            |
| Normal ürün                                                                                          | 35                 | 8.9             | Toplam                                                               | 394                | 100             |
| <b>Toplam</b>                                                                                        | <b>394</b>         | <b>100</b>      | <b>Coğrafi işaretli olan bir ürüne ödemeye istekli olunan miktar</b> |                    |                 |
| <b>Ezine peynirinin fiyatı hakkında algı</b>                                                         |                    |                 | %5'den az                                                            | 42                 | 28.0            |
| Pahalı                                                                                               | 206                | 52.3            | %5-10 arası                                                          | 66                 | 44.0            |
| Normal                                                                                               | 105                | 26.6            | %11-15 arası                                                         | 24                 | 16.0            |
| Fikrim yok                                                                                           | 80                 | 20.3            | %16-20 arası                                                         | 13                 | 8.7             |
| Ucuz                                                                                                 | 3                  | 0.8             | %20'nin üzerinde                                                     | 5                  | 3.3             |
| Toplam                                                                                               | 394                | 100             | Toplam                                                               | 150                | 100             |

tercih ettiği belirlenmiştir. Yılmaz (2020) tarafından yapılan bir çalışmada fiyatları aynı olduğu takdirde tüketicilerin % 91'inin coğrafi işaret tescilli ürünü tercih edeceği, % 9'unun ise coğrafi işaret tescilli olmayan ürünü tercih edeceği ortaya konmuştur. Zuluğ (2010) tarafından yapılan bir çalışmada Ezine peyniri ve Ayvalık zeytinyağının muadillerine göre taleplerinin sırasıyla % 43 ve % 58 daha fazla olduğu tespit edilmiştir. Meral (2013) tarafından yapılan bir çalışmada tüketicilerin % 58.9'unun coğrafi işaret tescilli bir ürüne coğrafi işaret tescilli olmayan bir üründen daha fazla ödemeye istekli olduğu, % 41.2'sinin ise isteksiz olduğu belirlenmiştir. Yılmaz (2020) tarafından yapılan bir çalışmada tüketicilerin % 46'sının coğrafi işaret tescilli bir ürüne daha fazla ödeme istekliliğinin olduğu tespit edilirken % 54'ünün daha fazla ödemeye isteksiz olduğu tespit edilmiştir. Meral



(2013) tarafından yapılan bir çalışmada coğrafi işaret tescilli Gemlik zeytinine tüketicilerin % 47.7'sinin %21-50 ek ödeme isteğinin olduğu, % 9.4'ünün ise % 51 ve üzerinde ek ödeme istekliliğine sahip olduğu ortaya konmuştur. Zuluğ (2010) tarafından yapılan bir çalışmada tüketicilerin coğrafi işaret tescilli Ayvalık zeytinyağı için % 82, Ezine peyniri için ise 3.55 kat ek ödeme istekliliğinin olduğu belirlenmiştir. Sancak (2019) tarafından yapılan bir çalışmada tüketicilerin % 55.3'ünün Beypazarı kurusunun fiyatı hakkında fikrinin olmadığı, % 39.8'inin fiyatının normal olduğunu düşündüğü, % 2.9'unun ise fiyatının pahalı olduğunu düşündüğü, % 2'sinin ise fiyatının ucuz olduğunu düşündüğü tespit edilmiştir. Tüketicilerin % 61.7'sinin Çubuk turşunun fiyatı konusunda fikri olmadığı, % 34.8'inin fiyatının normal olduğunu düşündüğü, % 2.1'inin fiyatının ucuz olduğunu düşündüğü, % 1.4'ünün ise fiyatının pahalı olduğunu düşündüğü belirlenmiştir. Tüketicilerin % 67.4'ünün Kalecik karasının fiyatı hakkında fikri olmadığı, % 22.7'sinin fiyatının ucuz olduğunu düşündüğü, % 7.8'inin fiyatının pahalı olduğunu düşündüğü ve % 2.1'inin ise fiyatının pahalı olduğunu düşündüğü tespit edilmiştir.

**Tablo 5. Araştırma kapsamındaki tüketicilerden elde edilen yargıların KMO ve Bartlett's istatistikleri**

*Table 5. KMO and Bartlett's statistics of the judgments obtained from consumers within the scope of the research*

| Kriterler                                       | Değerler |
|-------------------------------------------------|----------|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy | 0.888    |
| Bartlett's Test of Sphericity                   |          |
| Khi Kare testi                                  | 5488.842 |
| P-değeri                                        | 0.000    |

**Tablo 6. Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma davranışı üzerinde etkili olması beklenen faktörlere göre dağılımı (%)**

*Table 6. Distribution of consumers within the scope of the research according to factors expected to have an impact on Ezine cheese purchasing behavior (%)*

|                                                                                                                          | Ölçek Ortalaması |
|--------------------------------------------------------------------------------------------------------------------------|------------------|
| Ezine peyniri özgün bir tada sahiptir.                                                                                   | 4.1              |
| Coğrafi işaretli Ezine peynirini çok takdir ediyorum.                                                                    | 4.0              |
| Ezine peyniri bölgede daha fazla istihdama yol açar                                                                      | 3.9              |
| Coğrafi işaretli Ezine peyniri satın almak, yerel tarımın gelişimine yardımcı olmamı sağlıyor.                           | 3.9              |
| Coğrafi işaretli Ezine peyniri satın almak yerel çiftçiyi desteklememe yardımcı oluyor.                                  | 3.9              |
| Coğrafi işaret olarak koruma Ezine bölgesini koruyor.                                                                    | 3.9              |
| Coğrafi işaretli Ezine peyniri yemek beni memnun ediyor.                                                                 | 3.9              |
| Ezine peyniri daha iyi bir tat sunar.                                                                                    | 3.9              |
| Ezine peynirinin coğrafi işaret sebebiyle izlenebilirliği mevcuttur.                                                     | 3.8              |
| Ezine peyniri, ürünün münhasırlığını korur.                                                                              | 3.7              |
| Fiyat, Ezine peyniri seçerken önemli bir kriterdir.                                                                      | 3.7              |
| Ezine peyniri, diğer tam yağlı peynirlerden farklıdır.                                                                   | 3.7              |
| Ezine peyniri diğer bölgelerdeki peynirlerden daha yüksek kalitededir.                                                   | 3.6              |
| Ezine peyniri diğer peynirlerden daha yüksek bir ürün kalitesi sunar.                                                    | 3.6              |
| Ezine peyniri, diğer benzer peynirlerden daha pahalıdır.                                                                 | 3.6              |
| Ezine peyniri, diğer peynir türleri ile karşılaştırıldığında gıda güvenliği esaslarına daha uygun olarak üretilmektedir. | 3.4              |
| Ezine peyniri, sahte taklitçi ürünlerin olasılığını azaltır.                                                             | 3.3              |
| Üzerinde Ezine peyniri yazan tüm peynirler Ezine peyniridir.                                                             | 2.7              |
| Benim için tam yağlı beyaz peynirlerin hepsi Ezine peyniridir.                                                           | 2.3              |

Kaiser-Meyer-Olkin (KMO) değeri, örneklemin faktör analizi için yeterli olup olmadığını belirlemek amacıyla kullanılır ve 0 ile 1 arasında değer alır. KMO'nun 0.50'den büyük olması istenir. KMO değeri 0.90 ile 1 arasında ise mükemmel, 0.80 ile 0.90 arasında ise iyi, 0.70 ile 0.80 arasında ise orta düzeyde kabul edilir (Field, 2000). Bu çalışmanın KMO değeri 0.888 olduğundan, örneklemin faktör analizi için iyi seviyede olduğu söylenebilir.

*Tablo 5*'te görüldüğü üzere, araştırmada değerlendirilen yargılardan elde edilen korelasyon matrisi birim matris olup olmadığı hipotezi reddedilmektedir (khi-kare=5488.842,  $p<0.01$ ). Bu sonuçlara göre, ele alınan 19 değişken için faktör analizinin yapılması uygundur.

Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma davranışı üzerinde etkili olması beklenen faktörlere göre dağılımı *Tablo 6*'da yer almaktadır. Buna göre ölçek ortalamaları incelendiğinde araştırma kapsamındaki tüketicilerin, “Ezine peyniri özgün bir tada sahiptir” (4.1), “Coğrafi işaretli Ezine peynirini çok takdir ediyorum” (4.0), “Ezine peyniri bölgede daha fazla istihdama yol açar” (3.9), “Coğrafi işaretli Ezine peyniri satın almak, yerel tarımın gelişimine yardımcı olmamı sağlıyor” (3.9), “Coğrafi işaretli Ezine peyniri satın almak yerel çiftiği desteklememe yardımcı oluyor” (3.9), “Coğrafi işaret olarak koruma Ezine bölgesini koruyor” (3.9), “Coğrafi işaretli Ezine peyniri yemek beni memnun ediyor” (3.9), “Ezine peyniri daha iyi bir tat sunar” (3.9), “Ezine peynirinin coğrafi işaret sebebiyle izlenebilirliği mevcuttur” (3.8), “Ezine peyniri, ürünün münhasırlığını korur” (3.7), “Fiyat, Ezine peyniri seçerken önemli bir kriterdir” (3.7), “Ezine peyniri, diğer tam yağlı peynirlerden farklıdır” (3.7), “Ezine peyniri diğer bölgelerdeki peynirlerden daha yüksek kalitededir” (3.6), “Ezine peyniri diğer peynirlerden daha yüksek bir ürün kalitesi sunar” (3.6) ve “Ezine peyniri, diğer benzer peynirlerden daha pahalıdır” (3.6) yargılarına katıldıkları ortaya konmuştur. Ayrıca araştırma kapsamındaki tüketicilerin “Ezine peyniri, diğer peynir türleri ile karşılaştırıldığında gıda güvenliği esaslarına daha uygun olarak üretilmektedir” (3.4), “Ezine peyniri sahte taklitçi ürünlerin olasılığını azaltır” (3.3) ve “Üzerinde Ezine peyniri yazan tüm peynirler Ezine peyniridir” (2.7) yargılarına kararsız kaldığı tespit edilmiştir. Bunun yanı sıra araştırma kapsamındaki tüketicilerin “Benim için tam yağlı beyaz peynirlerin hepsi Ezine peyniridir” (2.3) yargısına katılmadığı saptanmıştır.

**Tablo 7. Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma davranışı açısından faktör analizinde toplam açıklanan varyans**

Table 7. Total explained variance in factor analysis in terms of Ezine cheese purchasing behavior of consumers within the scope of the research

|    | Toplam Açıklanan Varyans |         |           |                |         |           |                      |         |           |
|----|--------------------------|---------|-----------|----------------|---------|-----------|----------------------|---------|-----------|
|    | Başlangıç Özdeğeri       |         |           | Asıl Toplamlar |         |           | Döndürülen Toplamlar |         |           |
|    | Toplam                   | Varyans | Kümülatif | Toplam         | Varyans | Kümülatif | Toplam               | Varyans | Kümülatif |
|    |                          | %       | %         |                | %       | %         |                      | %       | %         |
| 1  | 8.292                    | 43.640  | 43.640    | 8.292          | 43.640  | 43.640    | 3.853                | 20.280  | 20.280    |
| 2  | 2.392                    | 12.589  | 56.229    | 2.392          | 12.589  | 56.229    | 3.106                | 16.349  | 36.629    |
| 3  | 1.520                    | 8.003   | 64.232    | 1.520          | 8.003   | 64.232    | 2.463                | 12.961  | 49.590    |
| 4  | 1.256                    | 6.610   | 70.842    | 1.256          | 6.610   | 70.842    | 2.126                | 11.188  | 60.778    |
| 5  | 0.957                    | 5.035   | 75.878    | 0.957          | 5.035   | 75.878    | 1.739                | 9.154   | 69.932    |
| 6  | 0.775                    | 4.079   | 79.957    | 0.775          | 4.079   | 79.957    | 1.301                | 6.845   | 76.777    |
| 7  | 0.578                    | 3.043   | 83.000    | 0.578          | 3.043   | 83.000    | 1.182                | 6.223   | 83.000    |
| 8  | 0.485                    | 2.552   | 85.552    |                |         |           |                      |         |           |
| 9  | 0.408                    | 2.148   | 87.701    |                |         |           |                      |         |           |
| 10 | 0.376                    | 1.981   | 89.681    |                |         |           |                      |         |           |
| 11 | 0.348                    | 1.830   | 91.512    |                |         |           |                      |         |           |
| 12 | 0.291                    | 1.534   | 93.046    |                |         |           |                      |         |           |
| 13 | 0.275                    | 1.447   | 94.493    |                |         |           |                      |         |           |
| 14 | 0.267                    | 1.405   | 95.898    |                |         |           |                      |         |           |
| 15 | 0.220                    | 1.159   | 97.057    |                |         |           |                      |         |           |
| 16 | 0.174                    | 0.914   | 97.971    |                |         |           |                      |         |           |
| 17 | 0.174                    | 0.835   | 98.806    |                |         |           |                      |         |           |
| 18 | 0.140                    | 0.738   | 99.544    |                |         |           |                      |         |           |
| 19 | 0.087                    | 0.456   | 100.000   |                |         |           |                      |         |           |

Değişkenlere ait faktör yükleri ve değişkenlerin faktörlere göre dağılımları *Tablo 8*'de verilmiştir.

Cronbach Alpha değerine göre 19 adet 5'li Likert Ölçekli yargıdan oluşan genel ölçeğin oldukça güvenilir olduğu (0.911) ve tüketicilerin değişkenlere verdiği cevapların birbirinden farklı olduğu tespit edilmiştir.

Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma davranışı açısından faktör analizinde toplam açıklanan varyans *Tablo 7*'de verilmiştir. Buna göre 19 değişkenden elde edilen 7 faktörün toplam varyansı açıklama oranı % 83 olarak ortaya konmuştur.

**Tablo 8. Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma davranışı açısından faktör analizi sonuçları**

*Table 8. Factor analysis results in terms of Ezine cheese purchasing behavior of consumers within the scope of the research*

|                                                                                                                         | 1            | 2            | 3            | 4            | 5            | 6            | 7            |
|-------------------------------------------------------------------------------------------------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Ezine peyniri, bölgede daha fazla istihdama yol açar                                                                    | <b>0.873</b> | 0.161        | 0.084        | 0.148        | -0.004       | 0.040        | 0.146        |
| Coğrafi işaretli Ezine peyniri satın almak, yere tarımın gelişmesine yardımcı olmamı sağlıyor.                          | <b>0.828</b> | 0.259        | 0.151        | 0.216        | -0.020       | 0.082        | 0.093        |
| Coğrafi işaretli Ezine peyniri satın almak yerel çiftiği desteklememe yardımcı oluyor.                                  | <b>0.789</b> | 0.216        | 0.182        | 0.252        | -0.050       | 0.067        | 0.173        |
| Coğrafi işaret olarak koruma Ezine bölgesini koruyor.                                                                   | <b>0.782</b> | 0.335        | 0.043        | 0.194        | 0.016        | 0.150        | -0.091       |
| Ezine peynirinin coğrafi işaret sebebiyle izlenebilirliği mevcuttur.                                                    | <b>0.572</b> | 0.367        | 0.154        | 0.481        | -0.018       | 0.132        | -0.121       |
| Coğrafi işaretli Ezine peyniri yemek beni memnun ediyor                                                                 | 0.299        | <b>0.849</b> | 0.157        | 0.133        | 0.035        | 0.081        | 0.011        |
| Coğrafi işaretli Ezine peynirini çok takdir ediyorum                                                                    | 0.426        | <b>0.793</b> | 0.117        | 0.166        | -0.005       | 0.057        | -0.050       |
| Ezine peyniri özgün bir tada sahiptir                                                                                   | 0.270        | <b>0.720</b> | 0.063        | 0.207        | -0.198       | 0.200        | 0.328        |
| Ezine peyniri daha iyi bir tat sunar.                                                                                   | 0.168        | <b>0.715</b> | 0.287        | 0.215        | -0.052       | 0.145        | 0.287        |
| Ezine peyniri, diğer bölgelerdeki peynirlerden daha yüksek kalitededir.                                                 | 0.128        | 0.176        | <b>0.876</b> | 0.196        | 0.159        | -0.053       | 0.124        |
| Ezine peyniri, diğer peynirlerden daha yüksek bir ürün kalitesi sunar.                                                  | 0.158        | 0.200        | <b>0.872</b> | 0.227        | 0.100        | -0.015       | 0.133        |
| Ezine peyniri, sahte taklitçi ürünlerin olasılığını azaltır.                                                            | 0.380        | 0.214        | 0.103        | <b>0.739</b> | 0.216        | -0.012       | 0.128        |
| Ezine peyniri, ürünün münhasırlığını korur.                                                                             | 0.326        | 0.281        | 0.287        | <b>0.732</b> | 0.026        | 0.138        | 0.035        |
| Ezine peyniri diğer peynir türleri ile karşılaştırıldığında gıda güvenliği esaslarına daha uygun olarak üretilmektedir. | 0.345        | 0.145        | 0.469        | <b>0.602</b> | 0.194        | 0.060        | 0.057        |
| Benim için tam yağlı beyaz peynirlerin hepsi Ezine peyniridir.                                                          | -0.048       | -0.134       | 0.167        | 0.052        | <b>0.885</b> | 0.159        | -0.095       |
| Üzerinde Ezine peyniri yazan tüm peynirler Ezine peyniridir.                                                            | 0.000        | 0.027        | 0.069        | 0.150        | <b>0.863</b> | -0.066       | 0.267        |
| Fiyat, Ezine peyniri seçerken önemli bir kriterdir.                                                                     | 0.160        | 0.236        | -0.164       | 0.140        | 0.098        | <b>0.849</b> | -0.003       |
| Ezine peyniri, diğer benzer peynirlerden daha pahalıdır.                                                                | 0.119        | 0.066        | 0.517        | -0.061       | -0.001       | <b>0.624</b> | 0.332        |
| Ezine peyniri, diğer tam yağlı peynirlerden farklıdır.                                                                  | 0.140        | 0.211        | 0.284        | 0.079        | 0.187        | 0.107        | <b>0.814</b> |

Tüketicilerin Ezine peyniri satın alma davranışı üzerinde etkili olan faktörlerin adlandırılması *Tablo 9*'da verilmiştir. Buna göre kırsal kalkınma, tat ve memnuniyet, kalite, gıda güvenliği, ürünü tanıma, fiyat ve ürünü konumlandırma olmak üzere 7 faktör ortaya çıkmıştır.

Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma durumu üzerinde etkili olan değişkenlere yönelik lojistik regresyon analizi sonuçları *Tablo 10*'da yer almaktadır. Lojistik Regresyon modelinde bağımlı değişken tüketicilerin Ezine peyniri satın alma durumu olarak belirlenmiştir. Faktör Analizi sonucunda elde edilen 7 faktör de regresyon modeli içinde bağımsız değişken olarak kullanılmıştır. Modelin tamamının anlamlı olup olmadığını belirlemek amacıyla Hosmer & Lemeshow testi kullanılmıştır. Modelin anlamlı olabilmesi için sigma değerinin 0.05'ten büyük olması gerekmektedir. Buna göre Ezine peyniri satın alma durumu ile ilgili kurulan ikili

lojistik regresyon modeli tamamıyla anlamlı ve geçerli bir modeldir ( $0.371 > 0.05$ ). Lojistik regresyon analizi sonuçlarına göre araştırma kapsamındaki tüketiciler açısından Ezine peyniri satın alma durumu üzerinde istatistiksel olarak etkili olan bağımsız değişkenler tat ve memnuniyet faktörü, ürünü tanıma faktörü, ürünü

**Tablo 9. Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma davranışına ait faktör gruplarının adlandırılması**

*Table 9. Naming the factor groups of Ezine cheese purchasing behavior of consumers within the scope of the research*

| Değişkenler                                                                                                                                                                                                                                                                                                                                                                         | Faktör İsimleri                          |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| Ezine peyniri, bölgede daha fazla istihdama yol açar.<br>Coğrafi işaretli Ezine peyniri satın almak, yerel tarımın gelişmesine yardımcı olmamı sağlıyor.<br>Coğrafi işaretli Ezine peyniri satın almak yerel çiftçiye desteklememe yardımcı oluyor.<br>Coğrafi işaret olarak koruma Ezine bölgesini koruyor.<br>Ezine peynirinin coğrafi işaret sebebiyle izlenebilirliği mevcuttur | Kırsal Kalkınma Faktörü                  |
| Coğrafi işaretli Ezine peyniri yemek beni memnun ediyor.<br>Coğrafi işaretli Ezine peynirini çok takdir ediyorum.<br>Ezine peyniri özgün bir tada sahiptir.<br>Ezine peyniri daha iyi bir tat sunar.                                                                                                                                                                                | Tat ve Memnuniyet Faktörü                |
| Ezine peyniri diğer bölgelerdeki peynirlerden daha yüksek kalitededir.<br>Ezine peyniri, diğer peynirlerden daha yüksek bir ürün kalitesi sunar.                                                                                                                                                                                                                                    | Kalite Faktörü                           |
| Ezine peyniri, sahte taklitçi ürünlerin olasılığını azaltır.<br>Ezine peyniri, ürünün münhasırlığını korur.<br>Ezine peyniri, diğer peynir türleri ile karşılaştırıldığında gıda güvenliği esaslarına daha uygun olarak üretilmektedir.                                                                                                                                             | Gıda Güvenliği Faktörü                   |
| Benim için tam yağlı beyaz peynirlerin hepsi Ezine peyniridir.<br>Üzerinde Ezine peyniri yazan tüm peynirler Ezine peyniridir.                                                                                                                                                                                                                                                      | Ürünü Tanıma Faktörü                     |
| Fiyat, Ezine peyniri seçerken önemli bir kriterdir.<br>Ezine peyniri, diğer benzer peynirlerden daha pahalıdır.                                                                                                                                                                                                                                                                     | Fiyat Faktörü                            |
| Ezine peyniri diğer tam yağlı peynirlerden farklıdır.                                                                                                                                                                                                                                                                                                                               | Ürünü Konumlandırma (Ayrı Tutma) Faktörü |

konumlandırma (ayrı tutma) faktörü, cinsiyet, medeni durum ve aylık kişisel gelir olarak belirlenmiştir. Tat ve memnuniyet faktörü % 1 düzeyinde anlamlı bulunmuş ve katsayı işareti pozitifdir. Buna göre Ezine peynirinin daha iyi bir tada sahip olduğunu düşünen ve Ezine peynirinden memnun olan tüketicilerin Ezine peyniri satın alma durumunun Ezine peynirinin daha iyi bir tada sahip olduğunu düşünmeyen ve Ezine peynirinden memnun olmayan tüketicilere göre 2.479 kat daha fazla olduğu söylenebilmektedir. Ürünü tanıma faktörü % 1 düzeyinde anlamlı bulunmuş ve katsayı işareti negatiftir. Buna göre Ezine peynirini tanıyan tüketicilerin Ezine peynirini tanımayan tüketicilere göre Ezine peyniri satın alma durumunun 0.622 kat daha az olduğu görülmektedir. Ürünü tanıma faktörü altında yer alan “Benim için tam yağlı beyaz peynirlerin hepsi Ezine peyniridir” ve “Üzerinde Ezine peyniri yazan tüm peynirler Ezine peyniridir” yargılarına verilen cevaplara göre 5’li Likert ölçek ortalamaları sırasıyla

2.34 ve 2.68 olduğundan dolayı katsayının negatif çıkması normal görülmektedir. Ürünü konumlandırma (ayrı tutma) faktörü % 1 düzeyinde anlamlı bulunmuş ve katsayı işareti pozitifdir. Buna göre Ezine peynirini diğer peynirlerden ayrı tutabilen tüketicilerin Ezine peyniri satın alma durumunun Ezine peynirini diğer peynirlerden ayrı tutamayan tüketicilere göre 1.579 kat daha fazla olduğu söylenebilmektedir. Cinsiyet değişkeni % 1 düzeyinde anlamlı bulunmuş ve katsayı işareti pozitifdir. Buna göre kadınların erkeklerle kıyaslandığında Ezine peyniri satın alma durumu 2.124 kat daha fazladır. Medeni durum değişkeni % 5 düzeyinde anlamlı bulunmuş ve katsayı işareti pozitif bulunmuştur. Buna göre bekarların evlilerle kıyaslandığında Ezine peyniri satın alma durumunun 3.343 kat daha fazla olduğu görülmektedir. Aylık kişisel gelir değişkeni % 5 düzeyinde anlamlı bulunmuş ve katsayı işareti pozitifdir. Buna göre, aylık kişisel gelirdeki bir birimlik artış, tüketicilerin Ezine peyniri satın alma olasılığını 1.156 kat artırmaktadır.

**Tablo 10. Araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma durumu üzerinde etkili olan değişkenlere yönelik lojistik regresyon analizi sonuçları**

*Table 10. Logistic regression analysis results for variables affecting the Ezine cheese purchasing status of consumers within the scope of the research*

|                                          | B      | S.E.  | Wald   | df | Sig.     | Odds Oranı |
|------------------------------------------|--------|-------|--------|----|----------|------------|
| Sabit                                    | -3.868 | 2.156 | 3.219  | 1  | 0.073    | 0.021      |
| Kırsal Kalkınma Faktörü                  | -0.151 | 0.152 | 1.000  | 1  | 0.317    | 0.859      |
| Tat ve Memnuniyet Faktörü                | 0.908  | 0.162 | 31.370 | 1  | 0.000*** | 2.479      |
| Kalite Faktörü                           | 0.230  | 0.152 | 2.287  | 1  | 0.130    | 1.258      |
| Gıda Güvenliği Faktörü                   | 0.090  | 0.155 | 0.334  | 1  | 0.563    | 1.094      |
| Ürünü Tanıma Faktörü                     | -0.476 | 0.148 | 10.375 | 1  | 0.001*** | 0.622      |
| Fiyat Faktörü                            | -0.165 | 0.153 | 1.164  | 1  | 0.281    | 0.848      |
| Ürünü Konumlandırma (Ayrı Tutma) Faktörü | 0.457  | 0.151 | 9.095  | 1  | 0.003*** | 1.579      |
| Yaş                                      | 0.022  | 0.028 | 0.588  | 1  | 0.443    | 1.022      |
| Cinsiyet                                 | 0.754  | 0.287 | 6.914  | 1  | 0.009*** | 2.124      |
| Medeni Durum                             | 1.207  | 0.555 | 4.731  | 1  | 0.030**  | 3.343      |
| Çocuk Sahibi Olma Durumu                 | 0.544  | 0.645 | 0.712  | 1  | 0.399    | 1.724      |
| Hanede Yaşayan Kişi Sayısı               | 0.089  | 0.114 | 0.609  | 1  | 0.435    | 1.093      |
| Aylık Kişisel Gelir                      | 0.145  | 0.059 | 6.039  | 1  | 0.014**  | 1.156      |

\*\*\*% 1 düzeyinde anlamlı, \*\*% 5 düzeyinde anlamlı, \*% 10 düzeyinde anlamlı Cox&Snell  $R^2=0.237$ , Nagelkerke  $R^2=0.354$ ,  $X^2=106.350$  ( $p=0.000$ )

#### 4. Sonuç

Bu çalışmada Türkiye'deki tüketicilerin coğrafi işaretli ürün satın alma davranışlarını belirlemek amaçlanmıştır. Bu amaçla Türkiye genelini temsil etmesi açısından İstanbul, Ankara ve İzmir illerinden 394 tüketici ile çevrimiçi anket çalışması gerçekleştirilmiştir.

Faktör analizi sonuçlarına göre tüketicilerin Ezine peyniri satın alma davranışına ilişkin kullanılan 19 yargı kırsal kalkınma, tat ve memnuniyet, kalite, gıda güvenliği, ürünü tanıma, fiyat ve ürünü konumlandırma olmak üzere 7 faktöre ayrılmıştır. Elde edilen faktörler lojistik regresyon analizinde diğer bağımsız değişkenlere ek olarak bağımsız değişken olarak kullanılmıştır. Lojistik regresyon analizi sonuçlarına göre araştırma kapsamındaki tüketicilerin Ezine peyniri satın alma davranışını etkileyen bağımsız değişkenlerin cinsiyet, medeni durum, aylık kişisel gelir, ürünü konumlandırma faktörü, ürünü tanıma faktörü ile tat ve memnuniyet faktörü olduğu ortaya konmuştur. Tat ve memnuniyet faktörü Ezine peyniri satın alma olasılığını artırdığından ürünün tadını ve memnuniyeti artırmak için kalite ve tat geliştirme çalışmalarına odaklanılmalıdır. Ürünü tanıma faktörü ele alındığından Ezine peynirini tanıyanların satın alma olasılığının daha düşük olduğu belirlendiğinden ürünün tanıtımı ve bilinirliğini artırmak için pazarlama stratejileri geliştirilmelidir. Ürünü konumlandırma faktöründe Ezine peynirini diğer peynirlerden ayrı tutabilen tüketicilerin satın alma olasılığının daha fazla olduğu saptandığından pazarlama aşamasında Ezine peynirinin benzersiz ve farklı bir ürün olduğu vurgulanarak avantaj sağlanabilir. Ayrıca bekarlar ve kadınların Ezine peynirini satın alma olasılığının daha fazla olduğu tespit edildiğinden bu demografik gruplara odaklanarak pazarlama stratejileri bu gruplara odaklanarak geliştirilebilir. Aylık kişisel gelirin artması Ezine peynirini satın alma olasılığını artırdığından daha yüksek gelir seviyelerine sahip tüketicilere odaklanılabilir.

Sonuç olarak, bu lojistik regresyon analizi sonuçlarına dayalı olarak, ürün kalitesini artırmak, ürün bilinirliğini ve farklılığını vurgulamak, kadınlar, bekarlar ve yüksek gelir seviyelerine sahip tüketicileri hedeflemek tüketicilerin Ezine peyniri satın alma olasılığını artırabilir.

#### **Teşekkür**

Bu çalışma Çanakkale Onsekiz Mart Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi tarafından FYL-2021-3838 Nolu Araştırma Projesi olarak desteklenmiştir.

#### **Etik Kurul Onayı**

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#### **Çıkar Çatışması Beyanı**

Makale yazarları olarak aramızda herhangi bir çıkar çatışması olmadığını beyan ederiz.

#### **Yazarlık Katkı Beyanı**

Planlama: Yılmaz, A.M., Niyaz Altınok, Ö.C.; Materyal ve Metot: Yılmaz, A.M., Niyaz Altınok, Ö.C.; Veri toplama ve İşleme: Yılmaz, A.M., Niyaz Altınok, Ö.C.; İstatistiki Analiz: Yılmaz, A.M., Niyaz Altınok, Ö.C.; Literatür Tarama: Yılmaz, A.M., Niyaz Altınok, Ö.C., Tomar, O.; Makale Yazımı, İnceleme ve Düzenleme: Yılmaz, A.M., Niyaz Altınok, Ö.C.



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**Isolation of Beneficial Bacteria from Wheat Plant Rhizosphere and Determination of PGP (Plant Growth Promoting) Properties**

Buğday Bitkisi Rizosferinden Yararlı Bakterilerin İzolasyonu ve Bitki Büyümesini Teşvik Edici Özelliklerinin Belirlenmesi

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**Abstract**

Wheat, an important food and industrial product, is one of the most widely grown plants in the world. Environmentally friendly alternative methods are needed to increase plant productivity. Plant growth-promoting rhizobacteria (PGPR) directly or indirectly promote plant growth and production by actively colonizing plant roots. In the current study, 49 isolates were obtained from rhizospheric soil samples of wheat fields in 6 districts of Kırşehir (Akpınar, Boztepe, Kaman, Mucur, Akçakent, Çiçekdağı) in May 2019 and the isolates were identified biochemically and by MALDI-TOF mass spectrometry. The MALDI-TOF MS results showed that 49 isolates from 14 distinct genera could be identified. Among the isolates, *Bacillus*, *Pseudomonas*, and *Pseudarthrobacter* ranked first through third. Plant growth promoting properties of these isolates (inorganic phosphate solubilisation, siderophore production, nitrogen fixation, HCN (Hydrogen cyanide) production, IAA (Indole-3-acetic acid) production) were screened. Among 49 isolates, 4 isolates (MH-50-6, MH-50-7, MH-60-1, and MH-60-3) dissolved inorganic phosphate, and 13 isolates (MH-28-1, MH-34-3, MH-34-8, MH-39-1, MH-39-3, MH-39-7, MH-50-8, MH-55-3, MH-55-7, MH-55-9, MH-60-1, MH-60-3, MH-60-5) nitrogen fixed, on the other hand, 9 isolates (MH-34-5, MH-34-8, MH-39-5, MH-50-6, MH-50-7, MH-50-8, MH-55-6, MH-60-1, MH-60-3) produced siderophores, 8 isolates (MH-28-1, MH-34-2, MH-34-4, MH-34-5, MH-39-1, MH-55-3, MH-60-2, MH-60-5) produced HCN, while 4 isolates (MH-34-8, MH-50-4, MH-50-8, MH-55-9) was determined to produce IAA. In conclusion, indigenous PGPR (*Pseudarthrobacter oxydans* MH-34-8, *Pseudomonas jessenii* MH-50-8, *Arthrobacter crystallopoietes* MH-60-1, *Aromatoleum evansii* MH-60-3) isolates gave positive results for at least 3 plant growth-promoting properties. The present study is the first study on growth-promoting plants isolated from wheat in Kırşehir (Turkey). This study will illuminate the preparation of effective microbial fertilizer with local bacterial species that spread in the region and the availability of local culture collections.

**Keywords:** Wheat, PGPR, Beneficial bacteria, Rhizosphere

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## Öz

Önemli bir gıda ve sanayi ürünü olan buğday, dünyada yaygın bir şekilde yetiştirilen bitkilerden biridir. Bitki verimliliğini artırmak için çevre dostu alternatif yöntemlere ihtiyaç vardır. Bitki büyümesini teşvik eden rizobakteriler (PGPR), bitki köklerini aktif olarak kolonize ederek bitki büyümesini ve üretimini doğrudan veya dolaylı bir şekilde destekler. Bu çalışmada, Mayıs 2019'da Türkiye'de Kırşehir'in 6 ilçesinde (Akpınar, Boztepe, Kaman, Mucur, Akçakent, Çiçekdağı) buğday tarlalarının rizosferik toprak örneklerinden 49 izolat elde edilmiş ve izolatların biyokimyasal ve MALDI-TOF kütle spektrometrisi yöntemiyle teşhisleri yapılmıştır. MALDI-TOF MS sonuçlarına göre 14 farklı cinse ait 49 izolat tanımlanmıştır. 49 izolat içerisinde ilk üç sırada *Bacillus*, *Pseudomonas* ve *Pseudarthrobacter* cinsleri yer almaktadır. Bu izolatların bitki büyümesini teşvik edici özellikleri (inorganik fosfat çözünürlüğü, siderofor üretimi, azot fiksasyonu, HCN (Hydrogen cyanide) üretimi, IAA (Indole-3-acetic acid) üretimi) tarandı. 49 izolattan 4'ünün (MH-50-6, MH-50-7, MH-60-1, and MH-60-3) inorganik fosfatı çözdüğü, 13'ünün (MH-28-1, MH-34-3, MH-34-8, MH-39-1, MH-39-3, MH-39-7, MH-50-8, MH-55-3, MH-55-7, MH-55-9, MH-60-1, MH-60-3, MH-60-5) azot fiksasyonu yaptığı, 9'unun (MH-34-5, MH-34-8, MH-39-5, MH-50-6, MH-50-7, MH-50-8, MH-55-6, MH-60-1, MH-60-3) siderofor ürettiği, 8'inin (MH-28-1, MH-34-2, MH-34-4, MH-34-5, MH-39-1, MH-55-3, MH-60-2, MH-60-5) HCN ürettiği, 4'ünün (MH-34-8, MH-50-4, MH-50-8, MH-55-9) ise IAA ürettiği belirlendi. Sonuç olarak, yerli PGPR (*Pseudarthrobacter oxydans* MH-34-8, *Pseudomonas jessenii* MH-50-8, *Arthrobacter crystallopoietes* MH-60-1, *Aromatoleum evansii* MH-60-3) izolatları en az 3 bitki büyümesini teşvik edici özellikleri bakımından pozitif sonuçlar vermiştir. Bu çalışma, Kırşehir'de (Türkiye) buğdaydan izole edilen büyümeyi teşvik eden bitkiler üzerine yapılan ilk çalışmadır. Bu çalışma, bölgede yayılım gösteren yerel bakteri türleri ile etkili mikrobiyal gübre hazırlanmasına ve yerel kültür koleksiyonlarının varlığına ışık tutacaktır.

**Anahtar Kelimeler:** Buğday, PGPR, Yararlı bakteriler, Rizosfer

## 1. Introduction

With rapid population growth and industrialization, it has become necessary to differentiate between the continuation of traditional agricultural practices worldwide. Although people disregard human health in order to obtain more efficiency from the products they produce, they have not avoided trying different applications. Although agricultural production has increased at the desired rate as a result of these different applications, it has caused the destruction of nature and the environment in terms of the results it has produced and has led to the deterioration of the natural balance by increasing environmental pollution (Savci, 2012). An example of harmful applications made to obtain more yield is the use of chemical fertilizers in the soil for a long time (Pahalvi et al., 2021). Long-term, intensive and indiscriminate use of chemicals in agriculture; It has become a serious threat to human and environmental health, food security, biodiversity and agricultural sustainability (Kotan and Tozlu, 2021). Overused fertilizers cause deterioration of the effectiveness of microorganisms in the soil over time, eutrophication and nitrate accumulation in water, greenhouse gas effects, and heavy metal accumulation. In addition, gases such as  $N_2O$  and  $NO$ , which are formed as a result of the use of excessive amounts of nitrogen fertilizer, disrupt the structure of ozone in the stratosphere and cause its decomposition (Sönmez et al., 2008).

The plant root system is surrounded by millions of microorganisms in a nutrient-rich rhizosphere. The rhizosphere harbors a diverse array of living organisms, including bacteria, fungi, nematodes, protozoa, algae, and micro arthropods. Plant roots not only provide mechanical support and aid in the absorption of water and nutrients, but they also engage in the synthesis, accumulation, and secretion of diverse compounds (Walker et al., 2011; Tabassum et al., 2017). These compounds produced by plant roots have a heterogeneous structure and act as chemical attractants for actively used soil microbial communities. Some substances, such as amino acids, sugars, and aromatic acids secreted by plant roots, provide a good supply of energy and nutrients for bacteria in the rhizosphere, causing a larger microbial population to develop there than outside the region (Haas and Defago, 2005). A community of soil bacteria that competitively colonizes plant roots and stimulates growth, thus reducing the incidence of plant diseases, is called plant growth-promoting rhizobacteria (PGPR) (Kleopfer, 1978). Some of the most important known features of PGPRs are their ability to dissolve organic phosphorus, produce plant hormones, produce siderophores, increase systematic durability, bind free nitrogen in the atmosphere, produce phytohormones such as IAA, Gas, kinetin and reduce the ethylene level of the plant by producing auxin. These beneficial bacteria, known as PGPR, play a crucial role in disease resistance, nutrient absorption, root and shoot formation, seed germination, and environmental stress tolerance (Hayat et al., 2010; Esertaş et al., 2023). Studies on PGPR bacteria isolated from the rhizosphere of various plants in Turkey are rapidly increasing (Oral and Kotan, 2021; Çelik, 2023). Bacteria belonging to the genera *Pseudomonas* and *Bacillus* stand out for their plant growth-promoting traits as well as their biocontrol properties. For instance, Çelikten and Bozkurt (2018) reported that bacteria of these genera, isolated from the rhizosphere of wheat fields in Hatay, exhibited plant growth-promoting characteristics.

Sustainability in agriculture requires improving the soil's physical, chemical, and biological structure. Any environmentally friendly activity that increases biological activity and soil performance in the soil is of vital importance for agricultural sustainability. Therefore, PGPR-based local microbial fertilizers need to be developed and used in agriculture (Kenneth et al., 2019). Investigating locally plant growth-promoting (PGP) bacteria and utilizing them in agricultural practices is crucial for sustainable agriculture, not only regionally but also across the entire country, particularly in areas like Kırşehir, where wheat farming is extensively practiced. The aim of the current study is to determine the roles of the local strains that we isolated from the soils in Kırşehir in supporting plant growth and to create the microbial fertilizer inventory of the region.

## 2. Materials and Methods

### 2.1. Locations of soil samples

Kırşehir, with a surface area of 6.570 km<sup>2</sup>, is located in the Central Kızılırmak Section of the Central Anatolia Region. Ranking 53<sup>rd</sup> in Turkey in terms of surface area, Kırşehir land constitutes 0.8% of the country's land and 2.9% of the Central Anatolian Region's land (Figure 1).

The province, which has 6 districts (Akpınar, Boztepe, Kaman, Mucur, Akçakent, Çiçekdağı) in total, is located between 38° 50'-39° 50' north latitudes and 33° 30'-34° 50' east longitudes (Table 1). It has been determined that



366.073 hectares of 431.025 hectares of agricultural land exist in the province, which has an altitude of 985 m and annual precipitation of around 350-400 mm, is irrigable. An annual yield of 48.800 kg was obtained from wheat cultivated in all districts of Kırşehir, especially Boztepe and Çiçekdağı (Bayar et al., 2019).

**Table 1. Locations and altitudes of wheat rhizosphere samples**

| No | Isolates                                         | Location          | Altitude | Latitude     | Longitude    |
|----|--------------------------------------------------|-------------------|----------|--------------|--------------|
| 1  | <i>Bacillus atrophaeus</i> MH-28-1               | AKPINAR/ Centre   | 1126     | 39°26'49.4"N | 33°58'03.2"E |
| 2  | <i>Bacillus simplex</i> MH-28-2                  | AKPINAR/ Centre   | 1126     | 39°26'49.4"N | 33°58'03.2"E |
| 3  | <i>Bacillus simplex</i> MH-28-3                  | AKPINAR/ Centre   | 1126     | 39°26'49.4"N | 33°58'03.2"E |
| 4  | <i>Bacillus simplex</i> MH-28-4                  | AKPINAR/ Centre   | 1126     | 39°26'49.4"N | 33°58'03.2"E |
| 5  | <i>Bacillus megaterium</i> MH-28-5               | AKPINAR/ Centre   | 1126     | 39°26'49.4"N | 33°58'03.2"E |
| 6  | <i>Bacillus simplex</i> MH-28-6                  | AKPINAR/ Centre   | 1126     | 39°26'49.4"N | 33°58'03.2"E |
| 7  | <i>Bacillus simplex</i> MH-28-7                  | AKPINAR/ Centre   | 1126     | 39°26'49.4"N | 33°58'03.2"E |
| 8  | <i>Pseudomonas anguilliseptica</i> MH-28-8       | AKPINAR/ Centre   | 1126     | 39°26'49.4"N | 33°58'03.2"E |
| 9  | <i>Bacillus cereus</i> MH-34-1                   | KAMAN/İsahocalı   | 1280     | 39°25'00.6"N | 33°53'58.8"E |
| 10 | <i>Bacillus muralis</i> MH-34-2                  | KAMAN/İsahocalı   | 1280     | 39°25'00.6"N | 33°53'58.8"E |
| 11 | <i>Hafnia alvei</i> MH-34-3                      | KAMAN/İsahocalı   | 1280     | 39°25'00.6"N | 33°53'58.8"E |
| 12 | <i>Bacillus mojavensis</i> MH-34-4               | KAMAN/İsahocalı   | 1280     | 39°25'00.6"N | 33°53'58.8"E |
| 13 | <i>Bacillus sp LB</i> MH-34-5                    | KAMAN/İsahocalı   | 1280     | 39°25'00.6"N | 33°53'58.8"E |
| 14 | <i>Bacillus simplex</i> MH-34-7                  | KAMAN/İsahocalı   | 1280     | 39°25'00.6"N | 33°53'58.8"E |
| 15 | <i>Pseudarthrobacter oxydans</i> MH-34-8         | KAMAN/İsahocalı   | 1280     | 39°25'00.6"N | 33°53'58.8"E |
| 16 | <i>Bacillus atrophaeus</i> MH-39-1               | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 17 | <i>Bacillus cereus</i> MH-39-2                   | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 18 | <i>Weeksella virosa</i> MH-39-3                  | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 19 | <i>Bacillus pseudomycooides</i> MH-39-4          | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 20 | <i>Bacillus pumilus</i> MH-39-5                  | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 21 | <i>Actinomyces viscosus</i> MH-39-6              | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 22 | <i>Bacillus thuringiensis</i> MH-39-7            | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 23 | <i>Bacillus cereus</i> MH-39-8                   | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 24 | <i>Bacillus simplex</i> MH-39-9                  | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 25 | <i>Bacillus simplex</i> MH-39-10                 | MUCUR/Yeşilyurt   | 1080     | 39°05'54.7"N | 34°18'29.3"E |
| 26 | <i>Bacillus simplex</i> MH-50-1                  | AKÇAKENT/Mahsenli | 1268     | 39°34'10.6"N | 34°10'44.5"E |
| 27 | <i>Brevibacillus brevis</i> MH-50-2              | AKÇAKENT/Mahsenli | 1268     | 39°34'10.6"N | 34°10'44.5"E |
| 28 | <i>Brevibacillus parabrevis</i> MH-50-3          | AKÇAKENT/Mahsenli | 1268     | 39°34'10.6"N | 34°10'44.5"E |
| 29 | <i>Staphylococcus hominis</i> MH-50-4            | AKÇAKENT/Mahsenli | 1268     | 39°34'10.6"N | 34°10'44.5"E |
| 30 | <i>Bacillus megaterium</i> MH-50-5               | AKÇAKENT/Mahsenli | 1268     | 39°34'10.6"N | 34°10'44.5"E |
| 31 | <i>Bacillus mojavensis</i> MH-50-6               | AKÇAKENT/Mahsenli | 1268     | 39°34'10.6"N | 34°10'44.5"E |
| 32 | <i>Bacillus subtilis</i> MH-50-7                 | AKÇAKENT/Mahsenli | 1268     | 39°34'10.6"N | 34°10'44.5"E |
| 33 | <i>Pseudomonas jessenii</i> MH-50-8              | AKÇAKENT/Mahsenli | 1268     | 39°34'10.6"N | 34°10'44.5"E |
| 34 | <i>Bacillus simplex</i> MH-55-1                  | BOZTEPE/Külhüyük  | 1150     | 39°20'15.1"N | 34°15'47.0"E |
| 35 | <i>Bacillus simplex</i> MH-55-2                  | BOZTEPE/Külhüyük  | 1150     | 39°20'15.1"N | 34°15'47.0"E |
| 36 | <i>Bacillus atrophaeus</i> MH-55-3               | BOZTEPE/Külhüyük  | 1150     | 39°20'15.1"N | 34°15'47.0"E |
| 37 | <i>Bacillus simplex</i> MH-55-5                  | BOZTEPE/Külhüyük  | 1150     | 39°20'15.1"N | 34°15'47.0"E |
| 38 | <i>Bacillus pumilus</i> MH-55-6                  | BOZTEPE/Külhüyük  | 1150     | 39°20'15.1"N | 34°15'47.0"E |
| 39 | <i>Glutamicibacter arilaitensis</i> MH-55-7      | BOZTEPE/Külhüyük  | 1150     | 39°20'15.1"N | 34°15'47.0"E |
| 40 | <i>Bacillus simplex</i> MH-55-8                  | BOZTEPE/Külhüyük  | 1150     | 39°20'15.1"N | 34°15'47.0"E |
| 41 | <i>Pseudarthrobacter polychromogenes</i> MH-55-9 | BOZTEPE/Külhüyük  | 1150     | 39°20'15.1"N | 34°15'47.0"E |
| 42 | <i>Arthrobacter crystallopoietes</i> MH-60-1     | ÇİÇEKDAĞI/İbikli  | 1140     | 39°31'50.0"N | 34°20'36.0"E |
| 43 | <i>Paeniclostridium sordellii</i> MH-60-2        | ÇİÇEKDAĞI/İbikli  | 1140     | 39°31'50.0"N | 34°20'36.0"E |
| 44 | <i>Aromatoleum evansii</i> MH-60-3               | ÇİÇEKDAĞI/İbikli  | 1140     | 39°31'50.0"N | 34°20'36.0"E |
| 45 | <i>Bacillus simplex</i> MH-60-4                  | ÇİÇEKDAĞI/İbikli  | 1140     | 39°31'50.0"N | 34°20'36.0"E |
| 46 | <i>Citrobacter freundii</i> MH-60-5              | ÇİÇEKDAĞI/İbikli  | 1140     | 39°31'50.0"N | 34°20'36.0"E |
| 47 | <i>Paracoccus denitrificans</i> MH-60-6          | ÇİÇEKDAĞI/İbikli  | 1140     | 39°31'50.0"N | 34°20'36.0"E |
| 48 | <i>Bacillus megaterium</i> MH-60-7               | ÇİÇEKDAĞI/İbikli  | 1140     | 39°31'50.0"N | 34°20'36.0"E |
| 49 | <i>Bacillus cereus</i> MH-60-8                   | ÇİÇEKDAĞI/İbikli  | 1140     | 39°31'50.0"N | 34°20'36.0"E |



Figure 1. Locations of wheat rhizospheric soil samples (Kırşehir/Turkey)

## 2.2. Bacteria isolation and purification from rhizosphere soil samples

To isolate the bacterial samples for use in the study, soil samples were taken at a depth of 10 cm from the rhizosphere of wheat (*Triticum aestivum*) plants in Kırşehir and its districts in 2019. Each soil sample was labelled and brought to Microbiology Laboratory of Kırşehir Ahi Evran University and studied under aseptic conditions. The soil samples were homogenized by thorough mixing and serial dilutions of  $10^{-1}$ - $10^{-6}$  were prepared (Naseem and Bano, 2014). Inoculation was performed using the spreading method in Petri dishes containing a nutrient agar (Merck) medium. Petri dishes were incubated for 2-4 days at  $28 \pm 2^\circ\text{C}$  and after which they were examined and selected according to their distinct morphological characteristics at the end of the incubation, incubated at  $28 \pm 2^\circ\text{C}$  for 48 h, and inoculated on Petri dishes containing nutrient agar by the line sowing method to obtain a pure culture (Figure 2). A total of 49 pure isolates (Table 2) obtained at the end of the incubation were transferred to a nutrient broth (Merck) medium. Purified bacteria were stored in 50% (v/v) glycerol solution at  $-80^\circ\text{C}$  for future research.

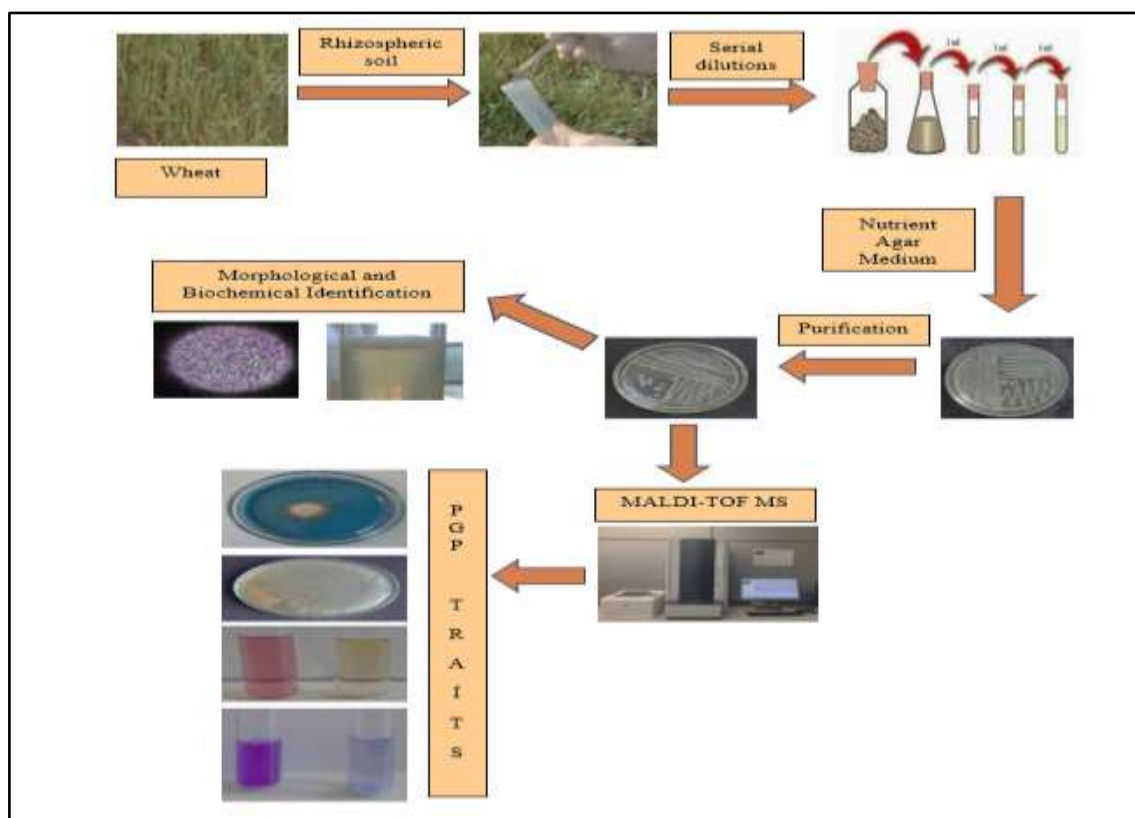


Figure 2. Flowchart representation of the process used to detect the characteristics of isolates from wheat rhizospheric soil

**Table 2. Numerical distribution of the isolates on the basis of genus**

| Genus    | Species                            | Number of Species | Genus             | Species                                  | Number of Species |
|----------|------------------------------------|-------------------|-------------------|------------------------------------------|-------------------|
| Bacillus | <i>Bacillus atrophaeus</i>         | 3                 | Pseudarthrobacter | <i>Pseudarthrobacter oxydans</i>         | 1                 |
|          | <i>Bacillus simplex</i>            | 14                |                   | <i>Pseudarthrobacter polychromogenes</i> | 1                 |
|          | <i>Bacillus megaterium</i>         | 3                 |                   | <i>Brevibacillus brevis</i>              | 1                 |
|          | <i>Bacillus cereus</i>             | 4                 | Hafnia            | <i>Brevibacillus parabrevis</i>          | 1                 |
|          | <i>Bacillus pumilus</i>            | 2                 |                   | <i>Hafnia alvei</i>                      | 1                 |
|          | <i>Bacillus mojavensis</i>         | 2                 | Actinomyces       | <i>Actinomyces viscosus</i>              | 1                 |
|          | <i>Bacillus thuringiensis</i>      | 1                 | Staphylococcus    | <i>Staphylococcus hominis</i>            | 1                 |
|          | <i>Bacillus muralis</i>            | 1                 | Glutamibacter     | <i>Glutamibacter arilaitensi</i>         | 1                 |
|          | <i>Bacillus pseudomycooides</i>    | 1                 |                   | <i>Arthrobacter crystallopoietes</i>     | 1                 |
|          | <i>Bacillus pumilus</i>            | 1                 | Paeniclostridium  | <i>Paeniclostridium sordellii</i>        | 1                 |
|          | <i>Bacillus subtilis</i>           | 1                 | Aromatoleum       | <i>Aromatoleum Evansii</i>               | 1                 |
|          | <i>Pseudomonas jessenii</i>        | 1                 | Paracoccus        | <i>Paracoccus denitrificans</i>          | 1                 |
|          | <i>Pseudomonas anguilliseptica</i> | 1                 | Weeksella         | <i>Weeksella virosa</i>                  | 1                 |
|          |                                    |                   |                   | <i>Citrobacter freundii</i>              | 1                 |
|          |                                    |                   | Citrobacter       |                                          |                   |

### 2.3. Biochemical tests and identification of isolates with MALDI-TOF MS

All isolates were grouped based on phenotypic and biochemical characteristics, such as cell form and size, Gram staining, motility, and the presence of catalase and oxidase, as described by Temiz (2010). MALDI-TOF mass spectrometer was used for bacterial identification (Figure 2). Microorganisms are identified by their unique molecular fingerprints by the MALDI Biotyper CA System. In this method, protein profiles of microorganisms' biomolecules (such as protein, peptide, sugar, polymer) are ionized and then passed through an electric and/or magnetic field. These profile spectra are compared graphically to reference microorganisms in the system's database to accurately identify them by genus and species. The table below displays the outcomes of the bacterial isolates identification using the MALDI-TOF MS method (Table 3).

### 2.4. Determination of plant growth promoting properties (PGP) of isolates

#### 2.4.1. Determination of nitrogen fixing capacity

The nitrogen fixation ability of the isolates was determined according to the protocol described by Wilson and Knight (1952). The isolates were incubated at 28±2°C for 24 h by streaking on NA (nutrient agar) medium. Each fresh culture isolate developed as a result of incubation was inoculated into petri dishes containing solid Burk's N-free medium by streaking (Wilson and Knight, 1952; Park et al., 2005). They were incubated in this medium at 28± 2 °C for four days, and the plates were checked daily and graded according to their development. Three time intervals were determined for nitrogen fixation activity (+++: development after 6 hours, ++: development after 12 hours, +: development after 24 hours).

#### 2.4.2. Confirmation of nitrogen fixation capabilities of isolates

Bacteria that grew and fixed nitrogen in Burk's N-free medium at 30°C after 3-4 days were grown in TSA (Tryptic Soy Agar) medium at 30±2°C for 24h. It was then inoculated into sterile test tubes containing 5 ml of semi-solid JNFb medium, according to the method described by Baldani et al. (2014). The uninoculated tubes were used as the control group, and the inoculated tubes were incubated for 7 days at 30±2°C. At the end of this incubation period, while there was no change in the tubes of the control group, it was evaluated by looking at the color change of the nitrogen-fixing bacteria in the existing medium and whether they formed a membrane layer near the surface of the medium; it was observed that the nitrogen fixation tubes changed color from yellow to blue and formed a zone near the surface of the medium.

**Table 3. Morphological, biochemical and MALDI TOF MS results of isolates**

| Location  | Isolates                                         | Gram Characteristic |        | Biochemical Characteristics |         | Motility | MALDI-TOF MS Score Value |
|-----------|--------------------------------------------------|---------------------|--------|-----------------------------|---------|----------|--------------------------|
|           |                                                  | Gram reaction       | KOH %3 | Catalase                    | Oxidase |          |                          |
| AKPINAR   | <i>Bacillus atrophaeus</i> MH-28-1               | +                   | *      | -                           | +       | +        | 2.188                    |
|           | <i>Bacillus simplex</i> MH-28-2                  | +                   | -      | -                           | +       | +        | 1.722                    |
|           | <i>Bacillus simplex</i> MH-28-3                  | +                   | -      | +                           | -       | +        | 1.775                    |
|           | <i>Bacillus simplex</i> MH-28-4                  | +                   | -      | +                           | -       | +        | 1.716                    |
|           | <i>Bacillus megaterium</i> MH-28-5               | +                   | -      | +                           | -       | +        | 1.584                    |
|           | <i>Bacillus simplex</i> MH-28-6                  | +                   | -      | +                           | -       | +        | 1.779                    |
|           | <i>Bacillus simplex</i> MH-28-7                  | +                   | -      | +                           | -       | +        | 1.743                    |
|           | <i>Pseudomonas anguilliseptica</i> MH-28-8       | -                   | -      | +                           | -       | +        | 1.497                    |
| KAMAN     | <i>Bacillus cereus</i> MH-34-1                   | +                   | -      | +                           | +       | +        | 1.489                    |
|           | <i>Bacillus muralis</i> MH-34-2                  | +                   | -      | +                           | +       | -        | 1.892                    |
|           | <i>Hafnia alvei</i> MH-34-3                      | -                   | -      | +                           | -       | +        | 1.478                    |
|           | <i>Bacillus mojavensis</i> MH-34-4               | +                   | -      | +                           | +       | +        | 1.912                    |
|           | <i>Bacillus sp. LB</i> MH-34-5                   | +                   | -      | +                           | -       | +        | 1.208                    |
|           | <i>Bacillus simplex</i> MH-34-7                  | +                   | -      | +                           | -       | +        | 1.750                    |
|           | <i>Pseudarthrobacter oxydans</i> MH-34-8         | +                   | -      | +                           | -       | +        | 2.086                    |
| MUCUR     | <i>Bacillus atrophaeus</i> MH-39-1               | +                   | -      | +                           | +       | +        | 1.891                    |
|           | <i>Bacillus cereus</i> MH-39-2                   | +                   | -      | +                           | +       | +        | 1.946                    |
|           | <i>Weeksella virosa</i> MH-39-3                  | -                   | -      | +                           | -       | -        | 1.394                    |
|           | <i>Bacillus pseudomycoides</i> MH-39-4           | +                   | -      | +                           | +       | +        | 1.704                    |
|           | <i>Bacillus pumilus</i> MH-39-5                  | +                   | -      | +                           | +       | +        | 1.535                    |
|           | <i>Actinomyces viscosus</i> MH-39-6              | +                   | -      | +                           | +       | -        | 1.461                    |
|           | <i>Bacillus thuringiensis</i> MH-39-7            | +                   | -      | +                           | -       | -        | 1.626                    |
|           | <i>Bacillus cereus</i> MH-39-8                   | +                   | -      | +                           | +       | +        | 1.747                    |
|           | <i>Bacillus simplex</i> MH-39-9                  | +                   | -      | +                           | -       | +        | 1.919                    |
|           | <i>Bacillus simplex</i> MH-39-10                 | +                   | -      | +                           | -       | +        | 1.849                    |
| AKÇAKENT  | <i>Bacillus simplex</i> MH-50-1                  | +                   | -      | +                           | -       | +        | 1.758                    |
|           | <i>Brevibacillus brevis</i> MH-50-2              | +                   | -      | +                           | +       | -        | 1.663                    |
|           | <i>Brevibacillus parabrevis</i> MH-50-3          | +                   | -      | +                           | +       | -        | 1.684                    |
|           | <i>Staphylococcus hominis</i> MH-50-4            | +                   | +      | -                           | +       | -        | 1.446                    |
|           | <i>Bacillus megaterium</i> MH-50-5               | +                   | -      | +                           | -       | +        | 1.637                    |
|           | <i>Bacillus mojavensis</i> MH-50-6               | +                   | -      | +                           | +       | +        | 2.052                    |
|           | <i>Bacillus subtilis</i> MH-50-7                 | +                   | -      | +                           | -       | +        | 1.430                    |
|           | <i>Pseudomonas jessenii</i> MH-50-8              | -                   | -      | +                           | +       | +        | 1.897                    |
| BOZTEPE   | <i>Bacillus simplex</i> MH-55-1                  | +                   | -      | +                           | -       | +        | 1.735                    |
|           | <i>Bacillus simplex</i> MH-55-2                  | +                   | -      | +                           | -       | +        | 1.709                    |
|           | <i>Bacillus atrophaeus</i> MH-55-3               | +                   | -      | +                           | +       | +        | 1.674                    |
|           | <i>Bacillus simplex</i> MH-55-5                  | +                   | -      | +                           | -       | +        | 1.712                    |
|           | <i>Bacillus pumilus</i> MH-55-6                  | +                   | -      | +                           | +       | +        | 1.831                    |
|           | <i>Glutamicibacter arilaitensis</i> MH-55-7      | +                   | -      | +                           | -       | +        | 2.309                    |
|           | <i>Bacillus simplex</i> MH-55-8                  | +                   | -      | +                           | -       | +        | 1.677                    |
|           | <i>Pseudarthrobacter polychromogenes</i> MH-55-9 | +                   | -      | +                           | -       | +        | 1.653                    |
| ÇİÇEKDAĞI | <i>Arthrobacter crystallopoietes</i> MH-60-1     | +                   | -      | +                           | +       | +        | 1.404                    |
|           | <i>Paenoclostridium sordellii</i> MH-60-2        | +                   | -      | +                           | +       | +        | 1.297                    |
|           | <i>Aromatoleum evansii</i> MH-60-3               | -                   | -      | +                           | +       | +        | 1.537                    |
|           | <i>Bacillus simplex</i> MH-60-4                  | +                   | -      | +                           | +       | +        | 1.544                    |
|           | <i>Citrobacter freundii</i> MH-60-5              | -                   | -      | +                           | -       | +        | 1.437                    |
|           | <i>Paracoccus denitrificans</i> MH-60-6          | -                   | -      | +                           | +       | +        | 1.301                    |
|           | <i>Bacillus megaterium</i> MH-60-7               | +                   | -      | +                           | +       | +        | 1.603                    |
|           | <i>Bacillus cereus</i> MH-60-8                   | +                   | -      | +                           | +       | +        | 1.338                    |

Note: \* +, positive; -, negative

**2.4.3. Determination of inorganic phosphate dissolving capacity of isolates**

The inorganic phosphate-dissolving capacities of the isolates were determined qualitatively according to the protocol described by Mehta and Nautiyal (2001). 25 microliters (approximately  $0.5 \times 10^9$  CFU ml<sup>-1</sup>) of pure bacterial cultures grown on nutrient agar medium were inoculated into tubes containing 5 ml of NBRIP-BPB Medium (National Botanical Research Institute's Phosphate), and the tubes with the control group were not inoculated. All tubes were incubated at 30±2°C and 180 rpm for three days. Although there was no color change

(blue-purple) in the control group tubes after incubation, it was observed that some of the inoculated tubes showed color expansion.

#### 2.4.4. Assessment of isolates producing siderophores

To determine whether the isolates produced siderophores, Schwyn and Neilands (1987) followed the procedure and used Chrome Azurol S agar in this method. The isolates were seeded onto the medium using the spot-seeding method and incubated for 4 days at  $28\pm 2^\circ\text{C}$ . At the end of the incubation, yellow-orange color formation around the bacteria was evaluated as a positive result, and the formed zone diameters (mm) were measured (Ögütçü and Avsar, 2020) (Figure 3). Three time intervals were determined for siderophore activity (+++: color change after 1h, ++: color change after 6h, +: color change after 24h).

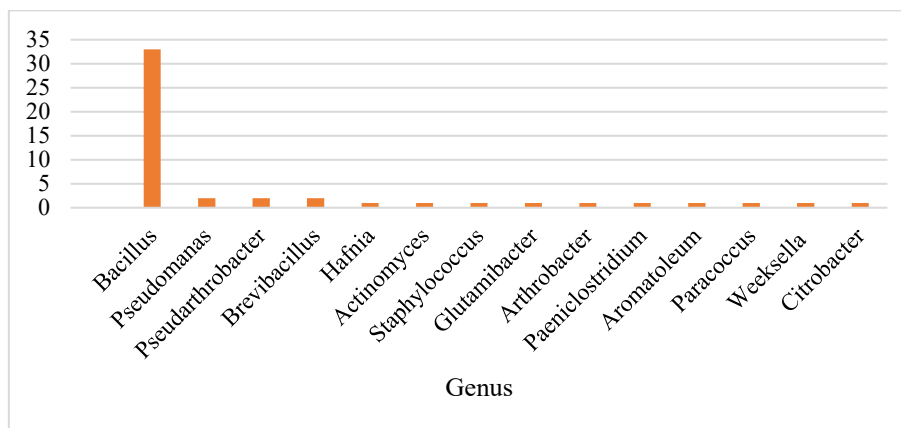


Figure 3. Number of PGPR isolates at genus level

#### 2.4.5. Evaluation of isolates producing (Hydrogen cyanide) HCN

The method suggested by Bakker and Schippers (1987) was used to determine the HCN production by the isolates. In accordance with this purpose, bacteria were inoculated on a nutrient agar medium containing 0.44% glycine, and filter papers (1.5 cm in diameter) impregnated with picric acid (0.5% picric acid, 2% sodium carbonate) were placed on the edge of the Petri plate without touching the medium. The mouths of the Petri dishes were tightly closed with paraffin and incubated at  $28\pm 2^\circ\text{C}$  for 4 days. At the end of the incubation period, picric acid-impregnated papers turned from yellow to brown, which was considered a positive result (Temiz, 2010). Three time intervals were determined for HCN activity (+++: color change after 6h, ++: color change after 12h, +: color change after 24h).

#### 2.4.6. Estimation of isolates producing indole-3-acetic Acid (IAA)

IAA production capabilities of the isolates were determined according to the protocol described by Sarwar and Kremer (1995). Bacteria were grown in a liquid culture for 10 min at 10,000 rpm. The cells were centrifuged, inoculated into 100 ml sterilized Luria Bertani and 0.01% g L-tryptophan medium (approximately  $0.5 \times 10^9$  CFU  $\text{ml}^{-1}$ ) in 250 ml flasks, and incubated for 3 days at  $30^\circ\text{C}$  and 180 rpm in a shaker. After incubation, bacterial cultures were centrifuged at 10,000rpm for 10 minutes. 2 ml of the supernatant was put into 10 ml tubes and 3 ml of Salkowski solution (0.5 M 1 ml  $\text{FeCl}_3$  and 50 ml of 98% perchloric acid) was added on it. The mixture was then left to stand for one hour in the dark at  $30^\circ\text{C}$ . After the waiting period, pink color change was considered positive for IAA production, and those that did not show color change were considered negative. It was evaluated as (+), (++), (+++) according to the lightening of the pink color change in the tube containing IAA.

#### 2.5. Statistical analysis

All the statistical analysis was performed by using JMP Pro Statistics Ver. 17 software. The statistical data were expressed as the mean of three independent replications  $\pm$  standard deviation (SD) of at least three replicates of each experiment and were interpreted through analysis of variance (one-way ANOVA) followed by Duncan's multiple range test at the  $P \leq 0.05$  significance level (Uzun et al., 2017).



### 3. Results and Discussion

#### 3.1. Identification of isolates

According to the MALDI-TOF MS results, 49 isolates belonging to 14 different genera were identified. *Bacillus*, *Pseudomonas*, and *Pseudarthrobacter* were in the first three ranks among the 49 isolates (Table 2, Figure 3).

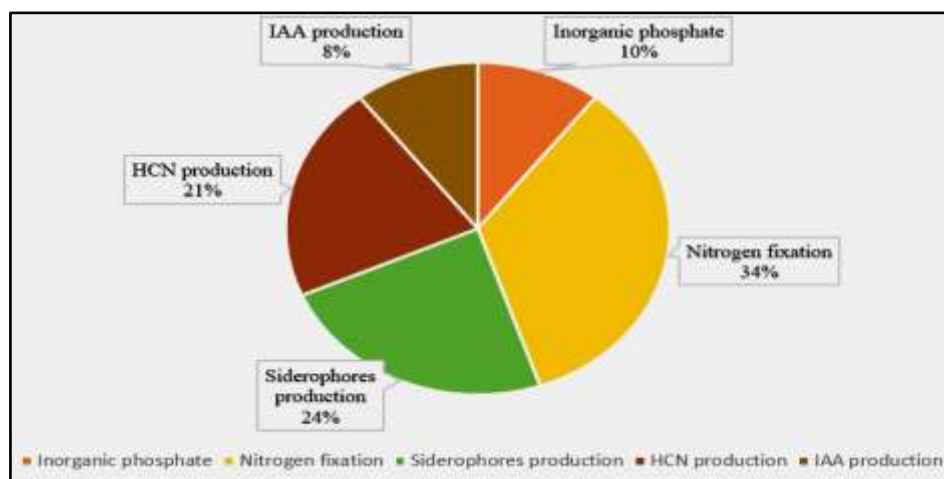


Figure 4. PGP ratios of isolates

#### 3.2. Biochemical and morphological characterization of isolates

49 isolates were obtained from the rhizospheric soil samples of the wheat fields in 6 districts (Akpınar, Boztepe, Kaman, Mucur, Akçakent, Çiçekdağı) of Kırşehir. All isolates except seven (*Pseudomonas anguilliseptica* MH-28-8, *Hafnia alvei* MH-34-3, *Weeksella virosa* MH-39-3, *Pseudomonas jessenii* MH-50-8), (*Aromatoleum evansii* MH-60-3, *Citrobacter freundii* MH-60-5 and *Paracoccus denitrificans* MH-60-6) showed Gram (+) reactions. The catalase test was positive for all isolates except *Staphylococcus hominis* MH-50-4, whereas the oxidase test was positive for 24 isolates. However, except for 7 isolates (*Bacillus muralis* MH-34-2, *Weeksella virosa* MH-39-3, *Actinomyces viscosus* MH-39-6, *Bacillus thuringiensis* MH-39-7, *Brevibacillus brevis* MH-50-2, *Brevibacillus parabrevis* MH-50-3 and *Staphylococcus hominis* MH-50-4) other isolates were observed to be mobil (Table 3).

#### 3.3. Screening for PGP characteristics of isolates

Of the 49 isolates, only 4 (MH-50-6, MH-50-7, MH-60-1, and MH-60-3) were found to dissolve inorganic phosphate. In addition, it was defined that 13 (MH-28-1, MH-34-3, MH-34-8, MH-39-1, MH-39-3, MH-39-7, MH-50-8, MH-55-3, MH-55-7, MH-55-9, MH-60-1, MH-60-3 and MH-60-5) of 49 isolates do nitrogen fixation, 9 (MH-34-5, MH-34-8, MH-39-5, MH-50-6, MH-50-7, MH-50-8, MH-55-6, MH-60-1 and MH-60-3) produce siderophores, 8 (MH-28-1, MH-34-2, MH-34-4, MH-34-5, MH-39-1, MH-55-3, MH-60-2 and MH-60-5) produce HCN, and 4 (MH-34-8, MH-50-4, MH-50-8 and MH-55-9) produce IAA (Table 4). Siderophore-producing isolates were analyzed by measuring zone diameter. The best siderophore-producing isolates are presented in Table 4. Isolates with high zone diameter are as follows in decreasing order: MH 60-1, MH- 60-3, MH-50-8, MH-55-6, MH 50-6, MH-50-7, MH 39-5, MH -34-8, MH-34-5.

Many studies have shown that different bacteria belonging to the *Pseudomonas*, *Bacillus*, *Rhizobium*, *Acinetobacter*, and *Paenibacillus* genera increase plant growth in the rhizosphere (Akhtar et al., 2009; Wang et al., 2013). *Pseudomonas* and *Bacillus* bacteria stand out with their plant growth-enhancing properties, as emphasized in numerous studies. *Bacillus*, a common soil genus, forms aerobic endospores and is considered the primary taxon cultivated from plant rhizospheres, accounting for 56.2% of soil bacteria (Sezen et al., 2016). Many research on inorganic phosphate solubility, HCN production, siderophore synthesis, nitrogen fixation, and IAA production of PGPRs in vitro have been undertaken (Baghaee and Heidarzadeh, 2014; Amara et al., 2015). Atmospheric nitrogen is converted to its (NH<sub>4</sub>) form, which can be used by plants by microorganisms for biological nitrogen fixation (BNF). The conversion of atmospheric nitrogen to ammonium is known as biological nitrogen fixation, or diazotrophy (Deka et al., 2015). According to the findings of Zaidi and Khan (2005) the application of various



**Table 4. PGP characteristics of isolates**

| Isolates                                         | Inorganic phosphate solubility | Nitrogen fixation | Siderophores production | Siderophores zone diameter (mm) | HCN production | IAA production |
|--------------------------------------------------|--------------------------------|-------------------|-------------------------|---------------------------------|----------------|----------------|
| <i>Bacillus atrophaeus</i> MH-28-1               | -                              | +                 | -                       | -                               | +              | -              |
| <i>Bacillus simplex</i> MH-28-2                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus simplex</i> MH-28-3                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus simplex</i> MH-28-4                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus megaterium</i> MH-28-5               | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus simplex</i> MH-28-6                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus simplex</i> MH-28-7                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Pseudomonas anguilliseptica</i> MH-28-8       | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus cereus</i> MH-34-1                   | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus muralis</i> MH-34-2                  | -                              | -                 | -                       | -                               | +              | -              |
| <i>Hafnia alvei</i> MH-34-3                      | -                              | +++*              | -                       | -                               | -              | -              |
| <i>Bacillus mojavensis</i> MH-34-4               | -                              | -                 | -                       | -                               | +              | -              |
| <i>Bacillus</i> sp. MH-34-5                      | -                              | -                 | +                       | 2.66±1.90e                      | +              | -              |
| <i>Bacillus simplex</i> MH-34-7                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Pseudarthrobacter oxydans</i> MH-34-8         | -                              | +                 | ++                      | 3.00±1.20de                     | -              | ++             |
| <i>Bacillus atrophaeus</i> MH-39-1               | -                              | +                 | -                       | -                               | +++            | -              |
| <i>Bacillus cereus</i> MH-39-2                   | -                              | -                 | -                       | -                               | -              | -              |
| <i>Weeksella virosa</i> MH-39-3                  | -                              | ++                | -                       | -                               | -              | -              |
| <i>Bacillus pseudomyoides</i> MH-39-4            | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus pumilus</i> MH-39-5                  | -                              | -                 | +                       | 4.33±1.83cde                    | -              | -              |
| <i>Actinomyces viscosus</i> MH-39-6              | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus thuringiensis</i> MH-39-7            | -                              | +                 | -                       | -                               | -              | -              |
| <i>Bacillus cereus</i> MH-39-8                   | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus simplex</i> MH-39-9                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus simplex</i> MH-39-10                 | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus simplex</i> MH-50-1                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Brevibacillus brevis</i> MH-50-2              | -                              | -                 | -                       | -                               | -              | -              |
| <i>Brevibacillus parabrevis</i> MH-50-3          | -                              | -                 | -                       | -                               | -              | -              |
| <i>Staphylococcus hominis</i> MH-50-4            | -                              | -                 | -                       | -                               | -              | +              |
| <i>Bacillus megaterium</i> MH-50-5               | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus mojavensis</i> MH-50-6               | +                              | -                 | +                       | 4.66±0.28cd                     | -              | -              |
| <i>Bacillus subtilis</i> MH-50-7                 | +                              | -                 | +                       | 4.33±0.12cde                    | -              | -              |
| <i>Pseudomonas jessenii</i> MH-50-8              | -                              | +                 | +                       | 7.00±1.90b                      | -              | +++            |
| <i>Bacillus simplex</i> MH-55-1                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus simplex</i> MH-55-2                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus atrophaeus</i> MH-55-3               | -                              | +                 | -                       | -                               | +              | -              |
| <i>Bacillus simplex</i> MH-55-5                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus pumilus</i> MH-55-6                  | -                              | -                 | +                       | 5.00±1.28c                      | -              | -              |
| <i>Glutamicibacter arilaitensis</i> MH-55-7      | -                              | +                 | -                       | -                               | -              | -              |
| <i>Bacillus simplex</i> MH-55-8                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Pseudarthrobacter polychromogenes</i> MH-55-9 | -                              | +                 | -                       | -                               | -              | +              |
| <i>Arthrobacter crystallopoietes</i> MH-60-1     | +                              | ++                | +                       | 10.33±0.79a                     | -              | -              |
| <i>Paeniclostridium sordellii</i> MH-60-2        | -                              | -                 | -                       | -                               | +              | -              |
| <i>Aromatoleum evansii</i> MH-60-3               | +                              | ++                | +                       | 8.33±0.77b                      | -              | -              |
| <i>Bacillus simplex</i> MH-60-4                  | -                              | -                 | -                       | -                               | -              | -              |
| <i>Citrobacter freundii</i> MH-60-5              | -                              | +++               | -                       | -                               | +              | -              |
| <i>Paracoccus denitrificans</i> MH-60-6          | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus megaterium</i> MH-60-7               | -                              | -                 | -                       | -                               | -              | -              |
| <i>Bacillus cereus</i> MH-60-8                   | -                              | -                 | -                       | -                               | -              | -              |

\*For nitrogen fixation activity (+++: development after 6 hours, ++: development after 12 hours, +: development after 24 hours).

\*\*For siderophore activity: (+++: color change after 1h, ++: color change after 6h, +: color change after 24h)

\*\*\*For HCN activity: (+++: color change after 6h, ++: color change after 12h, +: color change after 24h)

Data expressed as means ± standard deviation. Values with different letters differ significantly (P < 0.01)

strains of PGPR resulted in a significant increase in nitrogen uptake by the wheat shoot, ranging from 27% to 94%. Rana et al. (2011) determined that two of the 10 isolates, specifically *Providencia* sp., were obtained from the wheat rhizosphere. *Providencia* sp. AW4 and *Brevundimonas diminuta* AW7, demonstrated the most significant levels of activity in the nitrogen fixation test. In a study conducted by Sezen et al. (2016) it was found that out of a total of 180 bacteria that were isolated from the rhizosphere of wheat plants, 16 of them exhibited the ability to fix nitrogen. In the present study, 13 isolates (MH-28-1, MH-34-3, MH-34-8, MH-39-1, MH-39-3, MH-39-7, MH-50-8, MH-55-3, MH-55-7, MH-55-9, MH-60-1, MH-60-3 and MH-60-5) performed nitrogen fixation (Table 4). MH-63-7 (*Blastomonas natatoria*) and MH-64-3 (*Aromatoleum evansii*) isolates showed high levels of nitrogen fixation (Figure 5b). Among all isolates, the nitrogen-fixing isolates accounted for 34% (Figure 4).

Many bacteria can dissolve inorganic and organic phosphorus in the soil. These are known as phosphate-solubilizing bacteria (PSB). The presence of a significantly elevated population of phosphate solubilizing bacteria in the rhizosphere, as opposed to non-rhizospheric soil, has been well-established in previous studies (Patten and Glick, 2002). These bacteria dissolve phosphate through several mechanisms, particularly acid production. These bacteria release available phosphate into the soil by increasing the solubility of organic and inorganic P complexes. Some soil bacteria, such as *Pseudomonas* and *Bacillus*, can dissolve insoluble phosphates, which has a significant effect on plant growth-promoting activity (Mehnaz and Lazarovits, 2006). The utilization of *Bacillus* as a biofertilizer in the field of agriculture has been extensively documented. One inherent characteristic of *Bacillus* is its capacity to solubilize phosphate. *Bacillus polymyxa*, *Bacillus subtilis*, and various other species are recognized as highly proficient bacterial communities with regards to phosphate solubilization (Illmer and Schinner, 1992). Additionally, there have been reports of inorganic phosphate solubilization by *Acinetobacter* sp. (Ogut et al., 2010; Chaihar and Lumyong, 2011). Mukhtar et al. (2017) determined that PSB5 (*Bacillus safensis*) and PSB12 (*Bacillus megaterium*) from wheat rhizosphere solubilized high phosphate levels (305.6, 217.2, and 148.1  $\mu\text{g ml}^{-1}$ ). In our study, isolates MH-50-6 (*Bacillus mojavensis*), MH-50-7 (*Bacillus subtilis*), MH-60-1 (*Arthrobacter crystallopoietes*) and MH-60-3 (*Aromatoleum evansii*) were shown to have inorganic phosphate solubilization ability (Figure 5a, Table 4). Among all isolates, the isolates with inorganic phosphate-dissolving ability were determined to be 10% (Figure 4).

Iron, which is an indispensable inorganic substance in all living organisms, is abundant in the Earth's crust in the form of ferric hydroxide in an insoluble form. Owing to the very low solubility of  $\text{Fe}^{+3}$  ions at neutral pH, they cannot be used by plants and soil bacteria. Therefore, bacteria eliminate this problem by producing siderophores. This process facilitates the accessibility of iron to plants while rendering it inaccessible to phytopathogens. Therefore, concurrently, the siderophore serves to safeguard the overall well-being of the plant (Erdem, 2013). According to Meyer (2000) various strains of *Pseudomonas* exhibit the capacity to synthesise significant quantities of siderophore. Rasuli et al. (2006) observed that a total of 201 strains of *Pseudomonas fluorescens*, which were obtained from the rhizosphere of wheat plants, demonstrated the ability to synthesise siderophores in their study. Recent research has shown that the use of bacteria that produce siderophores is linked to a notable rise in the amount of iron that plants absorb, which enhances the amount of chlorophyll, the area of leaves, and the rate of photosynthetic activity (Ehsan et al., 2022; Mushtaq et al., 2020). In the current investigation, siderophores were formed by the isolates MH-34-5, MH-34-8 (*Pseudarthrobacter oxydans*), MH-39-5 (*Bacillus pumilus*), MH-50-6 (*Bacillus mojavensis*), MH-50-7 (*Bacillus subtilis*), MH-50-8 (*Pseudomonas jessenii*), MH-55-6 (*Bacillus pumilus*), and MH-60-3 (*Aromatoleum evansii*) (Figure 5c, Figure 6, Table 4). If we compare the siderophore zone diameters of the isolates, the first three are *Arthrobacter crystallopoietes* MH-60-1, *Aromatoleum evansii* MH-60-3, *Pseudomonas jessenii* MH-50-8 isolates with zone diameters of 12mm, 9mm and 7mm, respectively (Figure 6). It has been demonstrated that 24% of isolates generate siderophores. Conversely, *Arthrobacter* sp. was found to produce siderophores by Sayyed et al. (2012). Likewise, we determined that the isolate of *Arthrobacter crystallopoietes* MH-60-1, generated siderophores.

Hydrogen cyanide (HCN) has been widely recognised for its significant contribution to the suppression of diseases. HCN production by soil bacteria is reported to play a role in disease suppression, as in the case of tobacco where *Pseudomonas fluorescens* helped suppression of black root rot disease (Haas and Defago, 2005). According to Siddiqui (2006), it has been reported that hydrogen cyanide (HCN) is a volatile secondary metabolic product that exhibits growth-suppressing properties against pathogens. This suppression is attributed to the inhibition of metal enzymes, particularly cytochrome c oxidases, within the electron transport system. Wani et al. (2007) reported that most rhizospheric isolates produced HCN and aided plant growth. El Habil-Addas et al. (2017) isolated RS15 (*Pantoea allii* strain BD 390) and RS 19 (*Stenotrophomonas maltophilia* strain IAM 12423) strains from wheat rhizosphere and determined that they produced HCN. When we examined the bacteria we isolated in terms of Hydrogen cyanide (HCN), it has been determined that the isolates MH-28-1 (*Bacillus atrophaeus*), MH-34-2 (*Bacillus muralis*), MH-34-4 (*Bacillus mojavensis*), MH-34-5 (*Bacillus* sp.), MH-39-1 (*Bacillus atrophaeus*), MH-55-3, MH-60-2 (*Paeniclostridium sordellii*), and MH-60-5 (*Citrobacter freundii*) possess the potential to produce HCN (Table 4, Figure 5d). HCN production was observed in 21% of isolates (Figure 4). Therefore, the use of HCN-producing bacteria as biopesticides offers an environmentally friendly approach for sustainable agriculture.

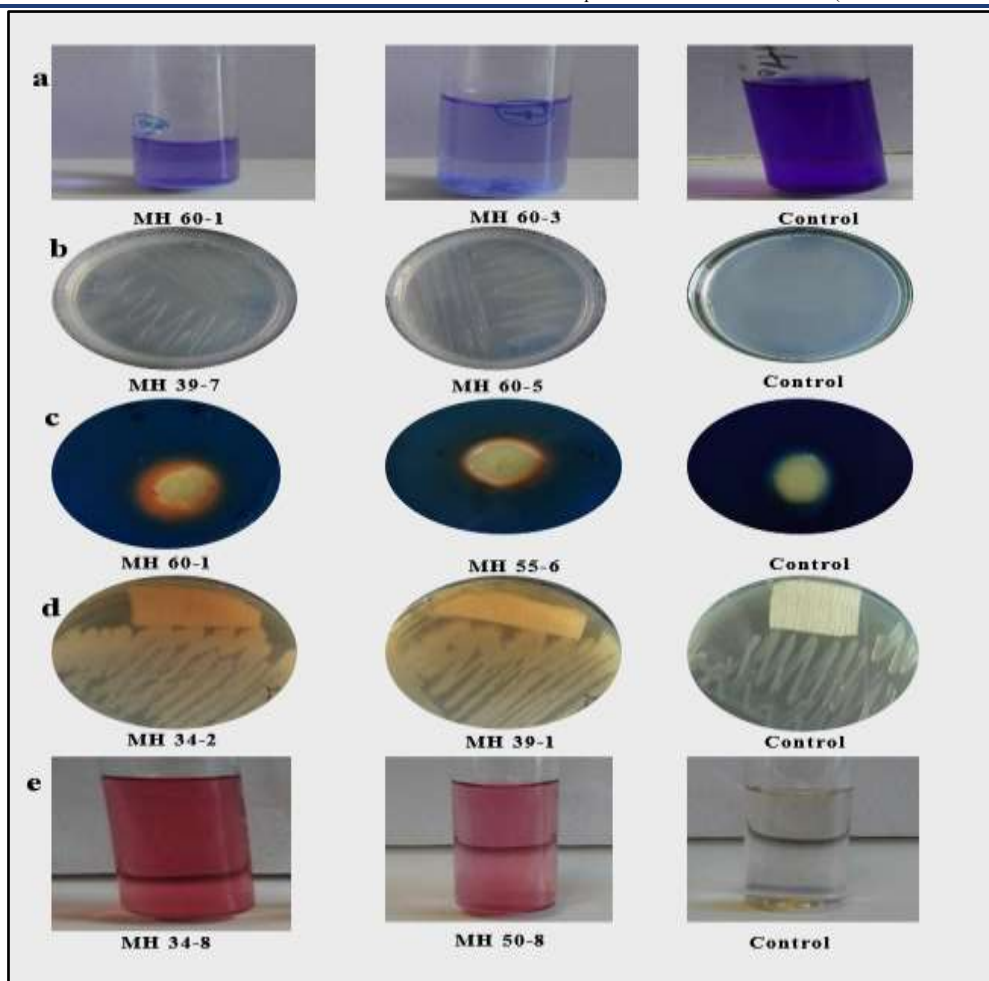


**Figure 5. PGP test images of isolates (a Inorganic phosphate solubility, b Nitrogen fixation, c Siderophores production, d HCN production, e IAA production)**

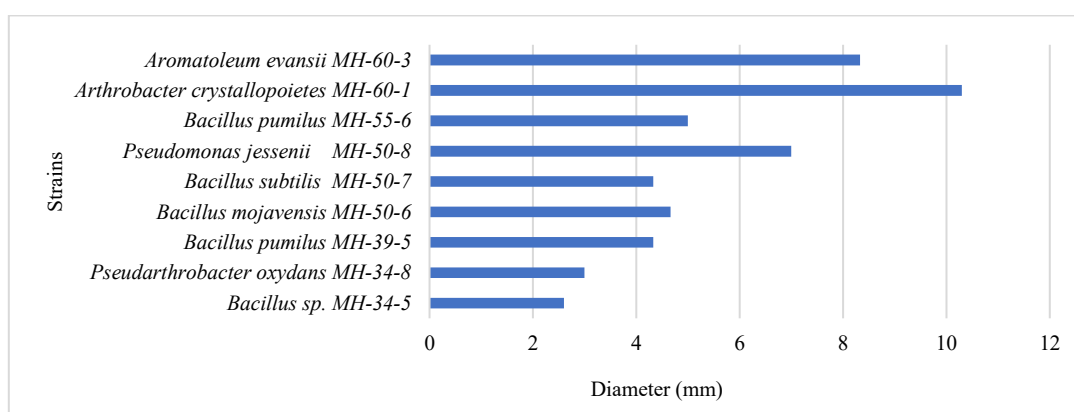


**Figure 6. Siderophore production zone diameters of isolates**

IAA (Indole-3-acetic acid), a member of the phytohormone group, is generally considered to be the most important natural auxin. IAA is the most active hormone involved in long-term physiological events, such as cell elongation, cell division, and differentiation in plants. It is estimated that 80% of bacteria isolated from the rhizosphere can produce IAA (Sokolova et al., 2011). Plant hormone producing microbes increase root surface area, leading to greater nutrient uptake, as reported by Bai et al. (2003). Numerous studies demonstrate the correlation between the promotion of plant growth by *Bacillus* spp. and the signalling of phytohormones (Faisal and Hasnain, 2006; López-Bucio et al., 2007; Baghaee and Heidarzadeh, 2014). In our current experiment, only four isolates MH-34-8 (*Pseudarthrobacter oxydans*), MH-50-4 (*Staphylococcus hominis*), MH-50-8

(*Pseudomonas jessenii*), and MH-55-9 (*Pseudarthrobacter polychromogenes*) were found to be IAA (Figure 5e). We found that it produces 8% (Figure 4).

#### 4. Conclusions

Some of our isolates gave positive results for at least one PGP (Plant growth promoting) trait (IAA production, nitrogen fixation, phosphorus solubilization, siderophore, HCN production). In light of these data, 22 of 49 isolates are positive for at least one PGP feature. Therefore, it appears that 45% of the isolates we obtained as a result of our study have the potential to be used in microbial fertilizer production.

Finally, the present investigation is the first to look at plant growth-promoting bacteria isolated from the soil of a local wheat rhizosphere in Kırşehir of Turkey. *Bacillus* phosphate-solubilizing and siderophore-producing bacteria dominate the wheat rhizosphere soil. The recovered bacteria are expected to be useful in organic agriculture as well as biofertilizer manufacture, which will promote plant development and provide the sustainability of agriculture. Therefore, further research on PGPR is necessary to help to create more effective local rhizobacterial strains that can function in several agro-ecological environments.

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#### Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

#### Conflicts of Interest

The authors declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

#### Authorship Contribution Statement

Concept: Güler, M.; Design: Ögütçü, H.; Data Collection or Processing: Güler, M.; Statistical Analyses: Numanoglu Çevik, Y.; Literature Search: Ögütçü, H.; Writing, Review and Editing: Güler, M.

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## Impact of Row Planters and Different Planting Arrangements on Peanut Yield and Yield Components

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### Abstract

Peanut (*Arachis hypogaea* L.) is one of the most important and economical oilseeds in the tropics and subtropics, playing a crucial role in both human nutrition and soil reclamation. This study aimed to evaluate the performance of various row planters and planting arrangements for mechanized peanut cultivation in the Moghan region of Iran using a randomized complete block design with six treatments and four replications over 2020 and 2021. The main objective was to identify the optimal planter configuration to enhance peanut yield. The treatments included different planting setups: T1 and T2 used a pneumatic single-row planter with 75 cm row spacing and 12 and 17 cm between plants, respectively. T3 and T4 applied a pneumatic twin-row planter (Tarashkadeh) with 75 cm between rows and 22 and 28 cm between plants, respectively, while T5 and T6 utilized a single-row planter with reduced row spacing of 50 cm and plant spacing of 25 and 30 cm. The results indicated that T4 and T3 provided the best horizontal uniformity of seed distribution (78.93% and 78.62%, respectively) and high emergence rates (94.23% and 93.08%). The twin-row configuration (T4) increased pod yield by 12.21% and 17.70% compared to the single-row patterns (T2 and T1). The twin-row planting system significantly improved plant density and pod yield, demonstrating its effectiveness over traditional single-row planting. Based on these findings, the use of a pneumatic twin-row planter (Tarashkadeh) with 75 cm row spacing and 28 cm plant spacing is recommended for farmers in the Moghan region to optimize peanut production.

**Keywords:** Peanuts, Pneumatic planter, Pod yield, Twin-row cultivation

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## 1. Introduction

Peanut (*Arachis hypogaea* L.) is one of the most important and economical oilseeds in the tropics and subtropics. Peanut distinguishes itself as a promising oil crop, benefiting from its affiliation with the legume family. Beyond its significance in human nutrition, peanuts play a crucial role in soil reclamation, leveraging the beneficial characteristics inherent to legumes (Önemli, 2005). This crop is rich in minerals, vitamins, fatty acids, fiber, and phenolic compounds. Peanut is a thermophilic plant that needs warm, sunny weather and a frost-free growing season (Aninbon et al., 2016; Abdzad Ghohari et al., 2018). The Moghan Plain, which is in northwestern Iran, is one of the places where peanuts are grown the most. Peanut seeds are commonly used for vegetable oil production and also for other products such as snack foods and peanut butter (Çalışkan et al., 2008; Kurt et al., 2017). Peanuts are considered the 13th most important food crop in the world and the 4th most important source of edible oil (FAOSTAT, 2022). China is the largest producer as well as consumer of groundnut in the world, with 17.6 million tonnes followed by India (6.7 million tonnes), Nigeria (4.4 million tonnes), and Sudan (2.8 million tonnes) (FAOSTAT, 2022). In the Moghan plain in northwest Iran, the area where peanuts are grown has grown a lot in recent years, from about 1.000 hectares in 2016 to more than 7.000 hectares in 2019, with a total production of 30.000 tonnes. As a result, Moghan Plain is Iran's first peanut cultivation and production area (Taghinazhad, 2019). The number of plants per unit area is one of the important yield determinants of field crops. As a result, planting density is one of the most important factors influencing peanut growth, yield, and quality (Kurt et al., 2017).

High-yield and efficient agricultural production requires reasonable plant-row spacing and planting strategies (Yang et al., 2017). Plantations with appropriate row spacing are among the most critical elements affecting peanut productivity (Awal and Aktar, 2015). If the planting density exceeds the optimum level, the available environmental factors may become insufficient to support the plant adequately. Conversely, if the planting density falls below the optimum level, the plant may struggle to fully harness the benefits of environmental factors (Ferahoğlu et al., 2023). Previous research in peanuts revealed that altering plant population and row pattern can affect canopy structure and light efficiency (Gardner and Auma, 1989), crop yield, quality factors, and pest development (Lanier et al., 2004; Lassiter et al., 2016), disease incidence and management (Wehtje et al., 1994; Maas et al., 2006; Tillman et al., 2006; Nuti et al., 2008), weed management (Place et al., 2010), physiological characteristics and yield (Rasekh et al., 2010), yield and yield components (Awal and Aktar, 2015; Kurt et al., 2017), leaf function and yield (Jun et al., 2021). Gardner and Auma (1989) reported that narrowing row spacing might improve peanut crop performance in low-temperature conditions during early vegetative growth. This change in crop structure should help with the expected use of resources (like light, water, and nutrients) and growth at the same time. The size of these responses is likely to change depending on how the plant grows (Haro et al., 2022). Peanut planting patterns have been single rows 70 cm apart. Therefore, conventional crop mechanization systems cannot increase plant density per unit area (Kurt et al., 2017). Previous research has shown that planting peanuts in twin-rows rather than single-rows can increase pod yield and total sound mature kernels by up to 450 kg ha<sup>-1</sup> (Baldwin et al., 2000; Beasley et al., 2000).

The twin-row pattern allows for greater spacing between individual plants, which in turn results in increased crop growth rate, enhances some market-grade attributes, reduces the occurrence of tomato spotted wilt tospovirus (TSWV) (Baldwin and Williams, 2002; Hurt et al., 2003; Tillman et al., 2006), and increases peanut pod yield (Lanier et al., 2004; Kurt et al., 2017; Yilmaz and Jordan, 2022). On the other hand, the type of planter used for planting is very important in terms of mechanical damage to the seed and uniformity of seed distribution (Celik et al., 2007; Yasir et al., 2012). According to Wehtje et al. (1994), vacuum-type planters were to be more precise and feature a better seed metering method. Kirk et al. (2013) demonstrated that although single-row mean pod yield in peanut was higher than twin-row, single-row mean harvested yield was lower but not statistically different. The traditional single-row planting of peanuts has been popular in Iran for many years, but the new twin-row method can be effective in increasing the yield and yield components of peanuts, as well as the mechanical parameters of the seeds.

The study aims to investigate and compare various row planters with distinct planting arrangements for mechanized peanut cultivation in the Moghan region of Iran. The primary objective is to identify the most effective planter that can enhance peanut yield, considering factors such as seed distribution uniformity and emerging percentage. The hypothesis suggests that specific planting patterns, particularly twin-row configurations, will lead

to improved pod yield compared to traditional single-row methods. Additionally, the study aims to assess the role of planter types, hypothesizing that certain types, like vacuum-type planters, may demonstrate superior precision in seed metering.

## 2. Materials and Methods

### 2.1. Experimental procedure

This study was conducted in the experimental field of the Ardabil Agricultural and Natural Resources Research and Education Center (Moghan Agricultural Research Station), Parsabad, Northwest of Iran (N 39°39' E 48°88' N, altitude=78 m) during the two growing seasons 2020-2021 using a randomized complete block design with six treatments in four replications. According to data from the Iran Meteorological Organization (IRIMO, 2021), this location has a semi-humid and somewhat warm climate. Over the previous 30 years, the average annual precipitation has been 251 mm, with the majority falling in the autumn and early spring. The region's annual precipitation is from 72.9 mm to 523 mm. The average annual high temperature is 35°C, while the average annual minimum is 8°C. The typical yearly relative humidity is around 71%. Climatic information about the experimental location is given in *Table 1*.

**Table 1. Meteorological data during the experimental years**

| Date      | 2020     |          |          |          |        | 2021     |          |          |          |        |
|-----------|----------|----------|----------|----------|--------|----------|----------|----------|----------|--------|
|           | Min (C°) | Max (C°) | Avr (C°) | Prc (mm) | Re (%) | Min (C°) | Max (C°) | Avr (C°) | Prc (mm) | Re (%) |
| May       | 11.3     | 22.9     | 17.1     | 42.9     | 72.8   | 13.5     | 27.2     | 20.3     | 16.9     | 67.4   |
| June      | 16.7     | 33.4     | 25.0     | 10.3     | 57.2   | 16.9     | 31.7     | 24.3     | 17.6     | 61.3   |
| July      | 19.7     | 34.1     | 26.9     | 0.6      | 57.2   | 21.7     | 36.3     | 28.0     | 0.0      | 53.6   |
| August    | 20.4     | 31.5     | 26.0     | 3.9      | 64.1   | 20.7     | 35.6     | 28.1     | 0.0      | 50.4   |
| September | 17.2     | 29.8     | 23.5     | 43.5     | 70.8   | 19.5     | 31.7     | 25.6     | 2.4      | 63.0   |
| October   | 12.9     | 24.1     | 18.5     | 29.2     | 74.2   | 12.3     | 21.6     | 17.0     | 42.8     | 74.7   |
| November  | 9.3      | 18.3     | 13.8     | 6.2      | 79.9   | 6.5      | 14.8     | 10.7     | 43.8     | 77.8   |

\*Min: Minimum monthly temperature; Max: Maximum monthly temperature; Avr: Average monthly temperature; Prc: Precipitation; Re: Average Relative Humidity.

**Table 2. Characteristics of row planters used in the experiment**

| Planter type                                                        | Number of planting units | Row spacing (cm) | Width (m) | Connection type | Cover and press wheel | Type of opener | Metering type  |
|---------------------------------------------------------------------|--------------------------|------------------|-----------|-----------------|-----------------------|----------------|----------------|
| Pneumatic row planter with spacing of 50 cm (SP-F4- 6 row)          | 6                        | 50               | 3         | mounted         | Open inner rubber     | runner         | Vertical plate |
| Pneumatic row planter with twin row (Tarashkadeh) (Sp /540 – 8 row) | 2×4                      | 75               | 3         | mounted         | Open inner rubber     | runner         | Vertical plate |
| Pneumatic row planter with spacing of 75 cm (WPHE- 4 row)           | 4                        | 75               | 3         | mounted         | Open inner rubber     | runner         | Vertical plate |

Each experimental plot had a 25×6 m dimension. The soil texture of the experimental field was clay-loam. The treatments were as follows: T1 and T2: planting by pneumatic single-row planter with spacing of 75 cm between rows and 12 and 17 cm between plants, respectively; T3 and T4: planting by pneumatic row planter with twin-row planter

(Tarashkadeh) with spacing of 75 cm between rows and 22 and 28 cm between plants, respectively; and T5 and T6: planting by pneumatic single-row planter with spacing of 50 cm between rows and 25 and 30 cm between plants, respectively. Therefore, the plant density for each treatment was as follows: T1: 11.11 plants per 1 m<sup>2</sup>, T2: 7.84 plants per 1 m<sup>2</sup>, T3: 12.12 plants per 1 m<sup>2</sup>, T4: 9.52 plants per 1 m<sup>2</sup>, T5: 8 plants per 1 m<sup>2</sup> and T6: 6.6 plants per 1 m<sup>2</sup>.

The method for preparing the land, which included disk harrowing and an experimental bedder, was the same in both years. During the cropping period, furrow irrigation was conducted around 4 to 5 times. An integrated approach to weed control was adopted, utilizing a combination of mechanical intervention using a cultivator and chemical measures, specifically applying 2 liters of trifluralin per hectare of pre-emergence herbicide before planting and hand weeding.

Traits including seed damage ratio, uniformity index of horizontal and vertical distribution of seeds, planting depth, emerging percentage, effective field capacity, yield, and yield components (number of pods per plant, pod length and diameter, 100-seed weight, and plant height) were measured. Grooves, overlays, and dispensers were similar in different treatments. The specifications of the planters used are given in *Table 2*.

## 2.2. Plant material

The local cultivar Goli was used in this study, with an average seed rate of 70 kg ha<sup>-1</sup>. The experiment was planted as a single seed in row planters.

## 2.3. Measurement methods

### 2.3.1. Seed damage ratio

The mechanical seed damage ratio was calculated using the following equation 1 formula (Taki and Asadi, 2009):

$$SDR = \frac{n}{N} \times 100 \quad (\text{Eq.1}).$$

Where SDR: seed damage ratio, n: number of damaged and broken seeds output from the distributor and N: total number of output seeds.

### 2.3.2. Effective field capacity

The effective field capacity (EFC) of a planter can be computed by dividing the area finished by the actual field time in hours (Taghinazhad, 2017).

$$EFC = \frac{A}{T_t} \quad (\text{Eq.2}).$$

Where: EFC: effective field capacity, A: area worked per hectare, T<sub>t</sub>: total time spent per hour

### 2.3.3. Seed germination percentage

Seed germination percentage was calculated from the formula 3 provided by Karayel and Ozmerzi (2002):

$$PE = \frac{Ste}{n} \times 100 \quad (\text{Eq.3}).$$

Where: PE: percentage of seed emergence; Ste: number of total emerged seedlings per meter; n: number of seeds sown per meter.

### 2.3.4. Horizontal uniformity of seed distribution

After all the seeds in each plot had grown, a digital measurer was used to measure the distance between plants in a parallel row at 20 random points from the middle of each plot. Then, the horizontal uniformity of seed distribution was calculated from the formula 4 and 5 that described by (Senapati et al., 1992).

$$sd_s = \sqrt{\frac{\sum_{i=1}^n S_i^2 - \frac{(\sum_{i=1}^n S_i)^2}{n}}{n-1}} \quad (\text{Eq.4}).$$

$$SSE = \frac{S_a - sd_s}{S_a} \quad (\text{Eq.5}).$$

Where  $SSE$ : the amount of uniformity,  $S_a$ : the mean of the measured distances,  $sd_s$ : the standard deviation of the distances,  $S_i$ : the distance measured at point  $i$ , and  $n$ : the number of samples (measurement intervals).

### 2.3.5. Vertical uniformity of seed distribution (seed placement depth)

After sowing, irrigation and germination of all sown seeds, plants were randomly removed from the ground at 20 points in each plot to measure the planting depth from the location of the seed to the part of the stem that was not green due to a lack of light. The vertical uniformity of seed distribution was figured out using the Senapati et al. (1992) formula 4 and 5.

### 2.3.6. Yield and yield components

Randomly picking 20 plants from each plot, yield components were measured, including the number of pods per plant and the weight of 100 seeds. Other morphological characteristics, such as plant height, pod length, pod diameter, grain length, and grain diameter, were also measured. To determine the yield per hectare, 5 samples of one square meter plots were harvested. The pods were hand-collected and weighed after drying. Final yields were adjusted to 7% moisture as described by Sorensen et al. (2004) and Yilmaz and Jordan (2022).

### 2.4. Data analysis

Outliers were detected before variance analysis using the Grubbs test. The Anderson-Darling test verified the normality of the data. Bartlette's test was used for the assumption of homogeneity of variance. Then a combined analysis of variances was performed using STAR statistical software (IRRI, 2013). The means were compared by Tukey's HSD (Honestly Significant Difference) at the 5% probability level.

## 3. Results and Discussion

The combined analysis of variance showed that Year had a significant effect on seed damage ratio, whereas Treatment and Year  $\times$  Treatment effects were non-significant (*Table 3*). The Year also had a non-significant effect on effective field capacity, while Treatment was significant (*Table 3*). The non-significant effects of Treatment and Year  $\times$  Treatment effects on the seed damage ratio were probably due to the similarity of the vacuum distributions among the planters, so the seed damage ratio resulting from mechanical damage to the seeds was low in all row planters tested. These results were in accordance with the findings of Jabir and Alfadilb (2022) who found that similar vacuum distributions among planters can reduce seed damage ratios by providing consistent seed pick-up, uniform distribution, and improved rows performance, enhancing planting efficiency and crop yield. Significant differences in some traits observed during the experimental years could be attributed to different weather conditions. In other words, the difference in the weather conditions of the experimental years had a significant effect on seed damage ratio, horizontal uniformity of seed distribution, vertical uniformity of seed distribution and planting depth traits but did not have a significant effect on effective field capacity and germination percentage. Tillman et al. (2006) and Yilmaz and Jordan (2022) reported similar results for significant effects of the year on some traits they studied. The means comparison for effective field capacity showed that T1 and T2 treatments had the highest effective field capacity (1.11 and 1.08 hectares per hour, respectively). T5 and T6 treatments were ranked second (0.96 and 0.94 hectares per hour, respectively), and T4 and T3 were ranked third (0.79 and 0.78 hectares per hour, respectively) (*Table 4*). Effective field capacity in a manually operated single-row planter for groundnut seeds studied by Singh and Moses (2021) was reported at 0.081 ha h<sup>-1</sup>. The results of Patil et al. (2004) study were 0.21 ha h<sup>-1</sup> for sugarcane cutter planter. Singh and Singh (2017) found that the effective field capacity (output) of the sugarcane cutter planter was 0.16 ha h<sup>-1</sup> and its performance was compared with the conventional method of planting. In their study, lower effective field capacity was related to the low forward speed (0.50 ms<sup>-1</sup>) of the tractor. They also reported that the effective field capacity of the planter (output) varied with the field and crop parameters. Variation in field capacity due to soil properties influences effective field capacity, impacting work width, forward speed, and time lost during agricultural operations (Ottoni Filho et al. 2014). Therefore, high levels of effective field capacity led to higher efficiency. In this experiment, single-row planters were higher than double-row planters.

The combined analysis of variance showed that Year, Treatment and Year  $\times$  Treatment had a significant effect on horizontal uniformity of seed distribution, whereas only Year had a significant effect on vertical uniformity of seed distribution and planting depth. The effects of Treatment and Year  $\times$  Treatment on germination percentage were also significant (Table 3).

**Table 3. Combined analysis of variance of the investigated planter's performance on peanut planting**

| Source of variations         | Df | Seed damage ratio   | Effective field capacity | Horizontal uniformity of seed distribution | Vertical uniformity of seed distribution | Germination percentage | Planting depth      |
|------------------------------|----|---------------------|--------------------------|--------------------------------------------|------------------------------------------|------------------------|---------------------|
| Year                         | 1  | 11.116*             | 0.011 <sup>ns</sup>      | 215.688**                                  | 267.907**                                | 0.262 <sup>ns</sup>    | 0.251*              |
| Replication (Year)           | 6  | 1.042               | 0.010                    | 8.643                                      | 15.586                                   | 5.371                  | 0.033               |
| Treatment                    | 5  | 0.437 <sup>ns</sup> | 0.154**                  | 84.425**                                   | 12.985 <sup>ns</sup>                     | 217.301**              | 0.033 <sup>ns</sup> |
| Year $\times$ Treatment      | 5  | 0.327 <sup>ns</sup> | 0.005 <sup>ns</sup>      | 34.538**                                   | 7.338 <sup>ns</sup>                      | 35.742**               | 0.025 <sup>ns</sup> |
| Error                        | 30 | 0.348               | 0.008                    | 7.350                                      | 6.416                                    | 8.103                  | 0.062               |
| Coefficient of Variation (%) | -  | 15.65               | 9.34                     | 3.57                                       | 3.95                                     | 3.26                   | 5.03                |

\* and \*\*: Significant at the 5% and 1% probability levels, respectively, and ns: non-significant

The mean comparison showed that treatments T4 (78.93%) and T3 (78.62%) demonstrated the highest horizontal uniformity in seed distribution, closely followed by T1 (78.20%) and T2 (76.36%). In contrast, treatments T5 (72.34%) and T6 (71.59%) exhibited lower levels of uniformity in seed distribution (Table 4). Differences among treatments in terms of horizontal uniformity of seed distribution can be related to the emerging percentage of the treatments (Table 4). A lower emerging percentage in single-row treatments compared to twin-row treatments resulted in a lower horizontal uniformity of seed distribution. In terms of emerging percentages, maximum values belonged to T4 and T3 treatments (94.23% and 93.08%), while minimum values belonged to T5 and T6 treatments (83.16% and 81.61%) (Table 4). In the twin-row planting system, due to the mutual placement of two vertical planes at an angle with a certain distance, zigzag planting on the row was possible to some extent, which was not possible for single-row planting. Therefore, with this method of planting, the poor emerging caused by planting a row of peanuts on the stack has been avoided. Zhang et al. (2023) reported that the twin-row planting in peanuts offers higher daytime net carbon uptake, water-use efficiency, and potentially greater yields compared to single-row planting. Twin-row planting in peanuts boosts pod yield by maximizing plant density, improving light interception, reducing branching, and potentially lowering pest effect, making it a more efficient cultivation approach (Yilmaz and Jordan, 2022).

**Table 4. Mean comparison of the investigated planter's performance on peanut planting**

| Treatment | Effective field capacity (ha. hr <sup>-1</sup> ) | Horizontal uniformity of seed distribution (%) | Emerging percentage (%) |
|-----------|--------------------------------------------------|------------------------------------------------|-------------------------|
| 2020      | 0.93 a                                           | 73.88 b                                        | 78.47 a                 |
| 2021      | 0.96 a                                           | 78.11 a                                        | 87.32 a                 |
| Treatment |                                                  |                                                |                         |
| T1        | 1.11 a                                           | 78.20 a                                        | 87.24 b                 |
| T2        | 1.08 a                                           | 76.36 a                                        | 85.06 bc                |
| T3        | 0.78 c                                           | 78.62 a                                        | 93.08 a                 |
| T4        | 0.79 c                                           | 78.93 a                                        | 94.23 a                 |
| T5        | 0.96 b                                           | 72.34 b                                        | 83.16 cd                |
| T6        | 0.94 b                                           | 71.59 b                                        | 81.61 d                 |

The means in each column followed by similar letter(s) are not significantly different at the 5% probability level, using the HSD Test

The combined analysis of variance showed that the Year was significant for plant height, pod number per plant, and pod yield. Treatment had a significant impact for pod number per plant, grain length, 100-grain weight, and pod yield. The Year  $\times$  Treatment interaction was also significant on pod number per plant and pod yield. Plant



height, pod length, pod diameter, and grain thickness were non-significant in terms of the treatments investigated (Table 5).

The results presented in Table 6 reveal significant variations among the treatments in terms of the measured field parameters. The mean comparison revealed that the T2 treatment (23.75) had the highest pod number per plant, whereas there were no significant differences among the T1, T5 and T6 treatments (Table 6). The lowest values belonged to T3 and T4 treatments that had no significant differences with T1, T5 and T6 treatments.

**Table 5. Combined analysis of variance of the investigated field parameters with different planters**

| Source of variations          | Df | Plant height        | Pod number per plant | Pod length          | Pod diameter        | Grain length        | Grain thickness     | 100-grain weight     | Pod yield    |
|-------------------------------|----|---------------------|----------------------|---------------------|---------------------|---------------------|---------------------|----------------------|--------------|
| Year                          | 1  | 11.530*             | 221.020**            | 0.000 <sup>ns</sup> | 0.000 <sup>ns</sup> | 0.004 <sup>ns</sup> | 0.016 <sup>ns</sup> | 38.324 <sup>ns</sup> | 5821973.86** |
| Replication (Year)            | 6  | 1.087               | 11.740               | 0.021               | 0.001               | 0.005               | 0.006               | 12.575               | 35042.38     |
| Treatment                     | 5  | 8.990 <sup>ns</sup> | 12.780*              | 0.024 <sup>ns</sup> | 0.009 <sup>ns</sup> | 0.151**             | 0.015 <sup>ns</sup> | 35.331**             | 864262.01**  |
| Year × Treatment              | 5  | 4.006 <sup>ns</sup> | 1.520*               | 0.020 <sup>ns</sup> | 0.001 <sup>ns</sup> | 0.037 <sup>ns</sup> | 0.004 <sup>ns</sup> | 1.490 <sup>ns</sup>  | 58746.10*    |
| Error                         | 30 | 3.999               | 5.043                | 0.021               | 0.003               | 0.016               | 0.019               | 6.933                | 18543.99     |
| Coefficient Of Variations (%) | -  | 4.33                | 10.06                | 7.20                | 7.67                | 7.72                | 18.86               | 2.53                 | 3.26         |

\* and \*\*: Significant at the 5% and 1% probability levels, respectively, and ns: non-significant

**Table 6. Mean comparison of the investigated field parameters with different planters**

|           | Pod number per plant | Grain length (cm) | 100-grain weight (g) | Pod yield (kg ha <sup>-1</sup> ) |
|-----------|----------------------|-------------------|----------------------|----------------------------------|
| Year      |                      |                   |                      |                                  |
| 2020      | 24.46 a              | 1.67 a            | 103.13 a             | 4521.54 a                        |
| 2021      | 22.17 b              | 1.65 a            | 104.92 a             | 3825.04 b                        |
| Treatment |                      |                   |                      |                                  |
| T1        | 22.62 ab             | 1.89 a            | 106.43 a             | 3823.12 c                        |
| T2        | 23.75 a              | 1.69 b            | 103.42 bc            | 4078.18 b                        |
| T3        | 20.75 b              | 1.51 c            | 101.40 c             | 4515.52 a                        |
| T4        | 20.76 b              | 1.54 c            | 102.02 bc            | 4645.42 a                        |
| T5        | 23.00 ab             | 1.63 bc           | 104.70 ab            | 3976.13 b                        |
| T6        | 23.00 ab             | 1.70 b            | 106.16 a             | 4001.25 b                        |

The means in each column followed by similar letter(s) are not significantly different at the 5% probability level, using the HSD Test.

For grain length, the highest values were recorded in the T1 (1.89 cm) and T2 (1.69 cm) treatments. Although T2 did not show significant differences from the T5 (1.63 cm) and T6 (1.70 cm) treatments, the lower grain length values were observed in T3 (1.51 cm) and T4 (1.54 cm), which were not significantly different from T5 (Table 6). Regarding 100-grain weight, the T1 (106.43 g) and T6 (106.16 g) treatments exhibited the highest values, while the lowest were found in T3 (101.40 g) and T4 (102.02 g). Treatments T2, T4, and T5 showed no significant differences in this parameter (Table 6). For pod yield, T4 (4645.42 kg ha<sup>-1</sup>) and T3 (4515.52 kg ha<sup>-1</sup>) treatments produced the highest yields, followed by T2 (4078.18 kg ha<sup>-1</sup>), T6 (4001.25 kg ha<sup>-1</sup>), and T5 (3976.13 kg ha<sup>-1</sup>), which showed no significant differences from one another. The lowest pod yield was observed in the T1 treatment (3823.12 kg ha<sup>-1</sup>) (Table 6). In terms of pod number per plant, the highest number was observed in 2020, with 24.46 pods per plant, while 2021 exhibited a lower value of 22.17 pods per plant. Among the treatments, T2 recorded the highest pod number (23.75), while T3 and T4 had the lowest values (20.75 and 20.76, respectively) (Table 6).

Results revealed that for T1 and T2, despite having more yield components than T3 and T4 treatments, the pod yield overall was higher in twin-row cultivation treatments compared to single-row cultivation. The reason for this result can be attributed to the presence of more plants per unit area in twin-row cultivation treatments than in single-row cultivation. Previous research has demonstrated that increased yields in twin-row planting are directly connected to more effective use of solar energy and other growth resources in narrowly spaced peanut crops, which translated into greater pod yields (Yaşlı et al., 2020).

One method for improving peanut yields without fostering excessive intra-row rivalry is to plant them in twin-rows, as described by Lassiter et al. (2016) and Mkandawire et al. (2021). Twin-row planting patterns have been found to produce higher yields than single-row planting patterns (Lanier et al., 2004).

Peanut production increases as the number of plants per unit area increases. The twin-row planting strategy allows farmers to boost plant density in the field by more than double, which is nearly unachievable with the standard single-row planting arrangement (Kurt et al., 2017). How well a plant population utilizes available environmental resources for growth is the primary determinant of crop yield. Plants benefited more from water, sunlight energy, and nutrients when there was less peanut plant density. Because of this, as the plant population declined, there was an increase in the number of pods per plant and the 100-grain weight (*Table 6*). These findings are consistent with those of Sorensen et al. (2004), Konlan et al. (2013), Dapaah et al. (2014), Kurt et al. (2017) and Mkandawire et al. (2021).

Finally, twin-row planting is a novel technology in peanut cultivation in Iran, with little study to record its influence on yield or yield characteristics. Traditionally, peanut planting patterns have consisted of single rows 75 cm apart, primarily with the local cultivar Goli. This study's findings suggest that boosting plant density per unit area by employing the twin-row planting pattern could be an efficient alternative to traditional single-row planting methods for optimizing yield.

#### **4. Conclusions**

The twin-row planting pattern exhibited superior performance with the highest horizontal uniformity of seed distribution and emerging percentage. The unique arrangement of two vertical planes at an angle, maintaining a specific distance, facilitated a zigzag planting configuration in the twin-row system, effectively avoiding the issues associated with poor emergence observed in the single-row planting method. Over the two-year study period, the twin-row pattern demonstrated an approximate 500 kg ha<sup>-1</sup> increase in pod yield compared to the single-row pattern. The heightened plant density in twin-row cultivation treatments contributed to the enhanced pod yield in comparison to single-row cultivation. Consequently, it is deduced that employing a pneumatic twin-row planter (Tarashkadeh) with a spacing of 75 cm between rows and 28 cm between plants is a more preferable and recommendable approach for peanut cultivation among Moghan farmers.

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#### **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

#### **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

#### **Authorship Contribution Statement**

Concept: Taghinezhad, J.; Design: Taghinezhad, J.; Data Collection or Processing: Taghinezhad, J.; Statistical Analyses: Zeinalzadeh-Tabrizi, H.; Literature Search: Taghinezhad, J., Zeinalzadeh-Tabrizi, H.; Writing, Review and Editing: Zeinalzadeh-Tabrizi, H.

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## Does Rice Importation Affect Production? Evidence from Nigeria

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## Abstract

Rice is an important staple food in Nigeria, playing a critical role in the country's food security, agricultural development, and economic growth. This research investigated how rice importation affected rice production and Nigeria's economic growth from 1990 to 2020 using time series data. The study aimed to understand the dynamics between rice importation, local production, and economic performance to inform policy decisions that promote agricultural sustainability. The data were analyzed with various econometrics models such as the trend model, Augmented Dickey-Fuller (ADF) test, Johansen Cointegration technique, Granger causality test, and simultaneous equation model. The results showed a significant gap between rice demand and supply in Nigeria and a long-run relationship between rice production, rice importation, and economic growth. While the gap indicated a high dependence on foreign rice to meet the rising domestic demand, the long-run relationship indicated that rice importation had a negative impact on the economy. The results also revealed causal relationships between rice production, rice importation, and GDP, and that rice importation had a negative and significant effect on Nigeria's economic growth and domestic rice production potential. Rice production in Nigeria was influenced by rice importation and population growth, while rice importation was affected by exchange rates and population growth. The study concluded that a sustained overdependence on rice importation has adverse consequences on Nigeria's economy and thereby suggested that the adoption of a multifaceted policy measure or strategy that emphasizes reducing rice importation, increasing domestic production of rice, and enhancing the standard of living for domestic rice producers is a key policy objective.

**Keywords:** Economic growth, GDP, Nigerian rice economy, Rice importation, Rice production

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## 1. Introduction

Despite the protracted state of economic stagnation, increasing poverty level, and deteriorating public infrastructure, Nigeria's economy remains the largest in Africa (Okonjo-Iweala and Osafo-Kwaako, 2007; Gyimah-Brempong et al., 2016). Nigeria's domestic economy is dominated by agriculture contributing about 40% of the GDP and employing two-thirds of the labour force (Onu et al. 2015; Gyimah-Brempong et al., 2016). Therefore, agricultural development is crucial for ensuring food security and reducing rural poverty in the country. The significance of agricultural development has long been acknowledged by the government of Nigeria as essential to achieving food self-sufficiency in the country. However, Nigeria's position as a net exporter of crude oil has been a major obstacle to the country's capacity to manage its agricultural development agenda, especially the growth of the rice subsector (Gyimah-Brempong et al., 2016).

Nigeria has the largest rice production in West Africa and the second-largest in Africa, with an average annual growth rate of 6.5% in the past few decades, surpassing other major producers in the region (Ogazi, 2010; KPMG, 2019). Nigeria also had more than half of the potential land area for rice cultivation and over 40% of the total rice output in West Africa in 2002 (FAOSTAT, 2011). However, Nigeria remains one of the top rice importers in the world, despite the abundant resources and the long history of government efforts to support the rice sector.

Nigeria's domestic rice demand significantly exceeds local production, with an average yearly shortfall of 2.4MMT recorded between 2007 and 2018 (KPMG, 2019). To keep up with the ever-growing domestic demand for rice, Nigeria resorts to importing rice from major rice-exporting countries to expand its total supply. However, the prospect for domestic rice production may be significantly impacted by the continued demand for imported rice. Over the past few decades, Nigeria has experienced sustained growth in rice consumption, resulting from an exponential population growth rate, increasing income level, and rapid urbanization (Ogazi, 2010; Ayanwale et al., 2011). Therefore, addressing the issue of how sustained demand will be met becomes a major concern. The only two ways to meet the increasing demand for rice are — boosting domestic production or importing more rice, but each option has a different impact on the economy. Continued growth in rice import in the country will not undermine local production, but will also override the agenda of attaining a self-sufficient state. A major contending issue is that Nigeria has a comparative advantage in rice production to at least meet its domestic consumption, but over-reliance on imports in recent years remains a great concern, particularly how the demand-supply for rice in the country may evolve in the future. Given the strategic position of the rice subsector in the economy of Nigeria, it is necessary to carry out this study to examine how rice importation influences rice production and economic growth in the country. The objectives of this research are to:

1. analyze the trend of Nigeria's rice output and imports;
2. estimate the rate of growth of Nigeria's rice output and rice imports;
3. identify the causal relationship among Nigeria's rice output, rice imports, and economic growth; and
4. examine the variables that affect Nigeria's rice output and rice imports.

## 2. Materials and Methods

### 2.1 Data Source

A 30-year period, from 1990 to 2020, was covered by the research using time-series data from secondary sources that were selected based on their validity and dependability. The data sources included the United States Department of Agriculture (USDA), World Bank, United Nations World Population Prospects, and World Bank, respectively, with data on rice output and importation, GDP, and population inflation in Nigeria.

### 2.2 Analytical Techniques and Model Specifications

Descriptive and inferential methods were employed in the research to analyze the collected data. The trend of Nigeria's rice importation and output was displayed using descriptive techniques like trend graphs and trend models. The study employed inferential methods such as the simultaneous equation model, unit root test, causality test, and co-integration test.



### 2.3 Trend Model

The trend model utilized in Gujarati and Porter (2009, as cited by Oyakhilomen et al., 2013; Biam and Adejo, 2017; Ukpe et al., 2018) was used to determine the growth rate and the direction of growth of Nigeria's rice production and rice importation from 1990 – 2020. The adopted model is specified as follows:

$$\gamma_t = \gamma_0 (1 + g)^t \quad (\text{Eq.1})$$

Where,  $\gamma_t$  = Quantity of rice produced and imported in year t measured in metric tonnes;

$\gamma_0$  = Quantity of rice produced and imported in the base year measured in metric tonnes;

$g$  = Compound rate of growth of rice production and rice imports;

$t$  = Time trend measured in years.

A semi-log trend model (equation 2) is obtained by taking the natural logarithm of equation (1)

$$\ln \gamma_t = \ln \gamma_0 + t \ln(1 + g) \quad (\text{Eq.2})$$

Given that,  $\ln \gamma_0 = \beta_0$ , and  $t \ln(1 + g) = \beta_1$

Hence, equation (2) can be rewritten as:

$$\ln \gamma_t = \beta_0 + \beta_1 t + \varepsilon_t \quad (\text{Eq.3})$$

Where,  $\beta_0$  = Intercept;

$\beta_1$  = slope or time trend coefficient;

$\varepsilon_t$  = random error term.

The growth rate models as specified by Akpaeti et al. (2013) obtained from parameters in equation (3) are expressed as:

$$r = \beta_1 \times 100 \quad (\text{Eq.4})$$

$$g = (e^{\beta_1} - 1) \times 100 \quad (\text{Eq.5})$$

Where,  $r$  = instantaneous growth rate

$g$  = compounded rate of growth

$e$  = Euler's number (2.71828)

The coefficient  $\beta_1$  shows the direction of growth. A positive or negative coefficient of  $\beta_1$  that is statistically significant means an increase or a decrease respectively in the growth rate of rice output and rice importation. A coefficient of  $\beta_1$  that is not significant statistically means no change in the rate of growth of rice output and rice importation.

### 2.4 Unit Root Test

For the model to be considered valid and reliable, the series must exhibit stationarity or unit root property (Maddala, 2002; Kong et al., 2014; Ghosh, 2021). The sequence of integration in the series was checked using the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979; Dickey and Fuller, 1981) to ensure that all of the model's variables were stationary. If a variable remains stationary at its level, it can be considered integrated of order zero, or  $I(0)$ . On the other hand, a variable is said to be integrated of order one or  $I(1)$  if it is steady at the first difference but not at its level. The following regression equation forms the basis of the ADF test:

$$\Delta S_t = \alpha + \beta_1 t + \beta_2 S_{t-1} + \sum_{i=1}^n \rho_i \Delta S_{t-i} + \varepsilon_t \quad (\text{Eq.6})$$

Where,  $S_t$  = series under consideration;

$\alpha$  = intercept or constant;

$\beta_1$  = time trend coefficient;

$n$  = number of lagged differences in the response variable;

$\Delta$  = operator for the first differencing;

Such that, the null hypothesis for unit root is given by  $H_0 : \beta_2 = 0$

### Co-integration Test

The long-run equilibrium relationship among rice production, rice imports, and GDP was tested using the Johansen co-integration technique (Johansen, 1988; Johansen and Juselius, 1990) based on the Vector Autoregressive (VAR) model. The co-integration test procedure is valid only if all the variables in the series are non-stationary and have the same order of integration at first differencing,  $I(1)$ .

Johansen and Juselius (1990) suggested two test statistics based on probability to determine the number of co-integrating vectors in the non-stationary series. These tests are called trace statistics and maximum eigenvalue statistics, and they are given by the following equation:

Based on the Vector Autoregressive (VAR) model, the Johansen co-integration technique (Johansen 1988; Johansen and Juselius, 1990) was used to investigate the long-run equilibrium relationship among rice output, rice imports, and GDP. Only when every variable in the series is non-stationary and has the same order of integration at initial differencing, or  $I(1)$ , is the co-integration test procedure valid.

Two test statistics based on probability were developed by Johansen and Juselius (1990) to find the number of co-integrating vectors in the non-stationary series. The following equation provides the results of these tests, which are known as trace statistics and maximum eigenvalue statistics, respectively.

$$\chi_{trace} = -K \sum_{j=r+1}^n \ln(1 - \chi_j) \quad (\text{Eq.7})$$

$$\chi_{max} = -K (1 - \chi_{r+1}) \quad (\text{Eq.8})$$

Where,  $\chi_i$  = estimated eigenvalue;

$K$  = number of observations usable;

$r$  = number of co-integrating vectors

### 2.5 Causality Test

The cointegration test does not indicate the direction of the relationship; it just identifies the presence of a long-run equilibrium relationship among the variables. The Granger causality test, developed by Granger (1988), was employed in the study to ascertain the direction of causality between two variables. In the Vector Error Correction (VEC) model, the Granger causality test indicates the direction of causality between GDP, rice imports, and rice production. There is a distinction between the long-run and short-run causality parameters in the VEC model. Using the VEC model, the causality between these three variables is estimated using the following functional forms:

$$\Delta Y_t = \alpha_1 + \sum_{d=1}^e \alpha_{1i} \Delta Y_{t-1} + \sum_{d=1}^e \beta_{1i} \Delta P_{t-1} + \sum_{d=1}^e \gamma_{1i} \Delta M_{t-1} + \alpha \mu_{t-1} + \varepsilon_{1t} \quad (\text{Eq.9})$$

$$\Delta M_t = \alpha_2 + \sum_{d=1}^e \alpha_{2i} \Delta Y_{t-1} + \sum_{d=1}^e \beta_{2i} \Delta P_{t-1} + \sum_{d=1}^e \gamma_{2i} \Delta M_{t-1} + \gamma \mu_{t-1} + \varepsilon_{2t} \quad (\text{Eq.10})$$

$$\Delta P_t = \alpha_3 + \sum_{d=1}^e \alpha_{3i} \Delta Y_{t-1} + \sum_{d=1}^e \beta_{3i} \Delta P_{t-1} + \sum_{d=1}^e \gamma_{3i} \Delta M_{t-1} + \beta \mu_{t-1} + \varepsilon_{3t} \quad (\text{Eq.11})$$

Where,  $Y, M, P$  = GDP, rice production, and rice imports respectively;

$\Delta Y, \Delta P, \Delta M$  = differential time series of GDP, rice production, and rice imports respectively;

$\mu_{t-1}$  = series' error correction term trailed by a period; and

$\varepsilon_i$  = random error term.

Note that the independent or explanatory variable is said to “Granger cause” the dependent variable if the coefficient of the error correction term or any of the lagged independent variables are significant. A long-term causal relationship between the independent and dependent variables is shown by a statistically significant and negative coefficient of the error correction terms.

## 2.6 Simultaneous Equation Model

The study adopted a simultaneous equation model to evaluate the determinants of rice production and rice imports in Nigeria. The simultaneous equation model was used because it allows the specification of more than one equation (Syahnur, 2012). The model is

$$M = \alpha_5 + \alpha_6 P + \alpha_7 INFL + \alpha_8 ER + \alpha_9 \quad (\text{Eq.12})$$

Apriori expectation:  $\alpha_6 < 0$ ,  $\alpha_7 < 0$ ,  $\alpha_8 < 0$ ,  $\alpha_9 > 0$

$$P = \alpha_0 + \alpha_1 M + \alpha_2 INFL + \alpha_3 ER + \alpha_4 POP + \mu \quad (\text{Eq.13})$$

Apriori expectation:  $\alpha_1 < 0$ ,  $\alpha_2 < 0$ ,  $\alpha_3 < 0$ ,  $\alpha_4 > 0$

Where M = Rice imports;

P = Rice production;

INFL = Domestic inflation;

POP = Population growth.

## 3. Results and Discussion

### 3.1 Trend in Nigeria's Rice Production and Importation (1990 – 2020)

The trend in Nigeria's rice production and importation is largely impacted by Nigeria's rice trade policies. These policies, according to Boansi (2013) and Abbas et al. (2018) are characterized by inconsistency resulting from the change of government. Nigeria in time has witnessed three significant trade policy epochs – the pre-ban period (1971 – 1984), the ban period (1985 – 1995), and the post-ban period (1996 – 2015). The pre-ban epoch is the period before the importation of rice into the country was completely prohibited. During the ban period, rice imports into the nation was completely restricted and any form of importation through the borders was considered illegal. This epoch was followed by the post-ban period during which the quantitative restriction on the importation of rice into the country was removed with the adoption of liberal trade policies to regulate rice imports. Nigeria's rice production and importation trend from 1990 to 2020 is represented in *Figure 1*. The figure shows an undulating uptrend in rice production between 1990 and 2020. The undulating characteristics of the trend line, however, can be attributed to inconsistent government policies. Rice production showed an increase from 1500000MT in 1990 to 1752000MT in 1995. This increase in production may be as a result of the Structural Adjustment Programme (SAP) which was introduced during the ban epoch to strengthen the restriction on rice importation. The increase in rice production continued into the post-ban period. Production also showed an increase in 1996 – 2000, followed by a decline in 2001. Following this decline in 2001, was an increase in production between 2002 and 2006. This rise in rice production could be attributed to the Presidential Initiative, which was launched within this period with the overarching goal of bridging the demand-supply gap in rice production. Nigeria's rice output, peculiarly, demonstrated an upward since the embargo period, growing from 1500000MT in 1990 to 4890000MT in 2020. However, this upward trend could be explained by the trade policy tools such as tariffs and import restrictions imposed during the period under study. The quantity of rice imported into the country during the period under investigation follows an uptrend pattern between 1990 – 2011 and a downtrend between 2011 – 2020. On the other hand, the quantity of rice imported into the country during the period under investigation follows an upward trend between 1990 – 2011 and a downward trend between 2011 – 2020 (*Figure 1*). Despite the embargo on rice imports into the nation from 1990 to 1995, there was still a noticeable upward trend in rice imports during this period which could be due to the significant quantity of rice smuggled through the country borders from neighboring countries (Munonye, 2016; Biam and Adejo, 2017). The figure also shows a notable increase in the quantity of rice imported in 2011. This might be as a result of the double levy expected to be imposed on rice imports in 2012 (USDA-FAS, 2013). The country, however, witnessed a significant drop in the quantity of rice imported between, 2011 – 2019 decreasing from 3200000MT in 2011 to 1400000MT in 2019. This could be as a result of the stringent

tariffs, outright ban, and restrictions imposed on rice imports within this period.

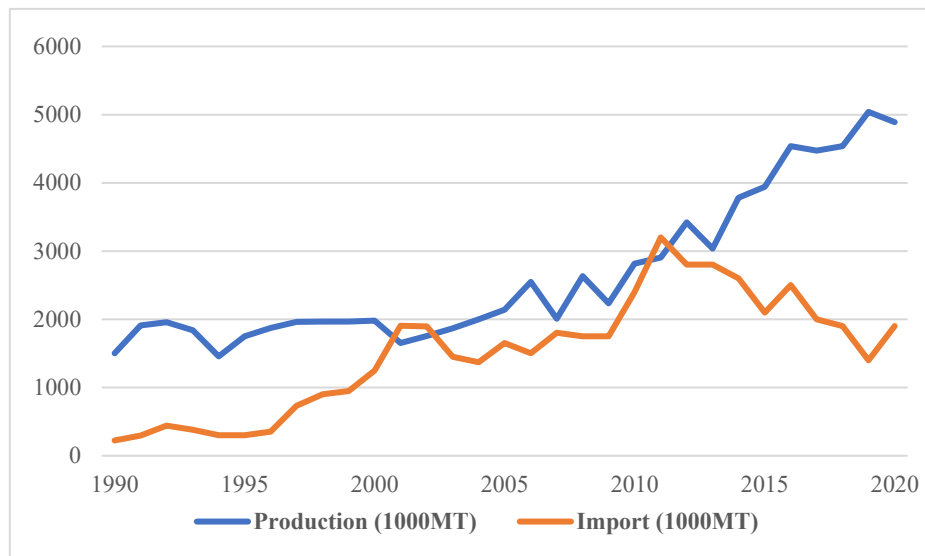


Figure.1. Trend in Nigeria's Rice Production and Rice imports

### 3.2 Growth Rate of Nigeria's Rice Output and Imports (1990 – 2020)

Table 1 displays the estimated growth model of Nigeria's rice imports and output for the period under investigation. At the 1% significance level, both rice production and rice imports had positive relationships with time trend. The result is consistent with Onu et al. (2015), who found that time trend was a key factor influencing Nigeria's domestic rice production and rice imports. According to the coefficient of multiple determination ( $R^2$ ) values in Table 2, time explains roughly 79% and 67%, respectively, of the variation in the growth trend of Nigeria's rice output and imports. This finding is consistent with that of Onu et al. (2015) who reported a high dependence of the growth in rice production and imports on time.

Table 1. Result Estimate for Growth Model of Nigeria's Rice Production and Rice Imports

| Variables       | Constant ( $\beta_0$ )   | Trend coefficient ( $\beta_1$ ) | $R^2$ | F-ratio    |
|-----------------|--------------------------|---------------------------------|-------|------------|
| Rice Production | -152.351***<br>(-7.339)  | 0.048***<br>(0.022)             | 0.792 | 74.802***  |
| Rice Imports    | -213.504***<br>(-12.414) | 0.084***<br>(0.041)             | 0.671 | 102.396*** |

### 3.3 Instantaneous and Compound Growth Rate for Nigeria's Rice Production and Rice Imports

Table 2 shows the instantaneous and compound growth rate of rice output and rice imports in Nigeria. Both rates are positive and significant at 1% probability level for both output and imports, which means that rice production and rice imports are increasing every year. However, the rates are higher for imports than output, which indicates that rice demand is outpacing domestic supply in Nigeria. This is consistent with Oyakhilomen et al. (2013) who found that rice consumption is growing at a faster rate than rice production in Nigeria. This implies that Nigeria has to rely on imports to meet the rising demand for rice in the country. Therefore, the higher growth rate of rice imports reflects the gap between rice demand and supply in Nigeria.

Table 2. Estimated Instantaneous and Compound Growth Rate for Domestic Rice Output and Rice Imports in Nigeria

| Variables       | $\beta_1$ | Instantaneous growth rate (%) | Compound growth rate (%) |
|-----------------|-----------|-------------------------------|--------------------------|
| Rice Production | 0.048***  | 4.8                           | 4.91                     |
| Rice Imports    | 0.084***  | 8.4                           | 8.76                     |

### 3.4 Direction of causality in rice production and rice importation in Nigeria (1990 – 2020)

#### Unit Root Test

According to the unit root test result (Table 3), the variables of rice output, rice imports, and GDP are not stationary at their level, but they become stationary at their first difference. This means that the variables have a unit root and they are integrated of order one. The next step is to test whether the variables have a long-run relationship or not. This can be done by using the co-integration test.

**Table 3. Unit Root Test Result**

| Variables       | ADF Statistics | p-value | Order of Integration | Status     |
|-----------------|----------------|---------|----------------------|------------|
| Rice production | -9.180818***   | 0.0000  | I(1)                 | Stationary |
| Rice imports    | -5.190477***   | 0.0002  | I(1)                 | Stationary |
| GDP             | -5.557947***   | 0.0001  | I(1)                 | Stationary |

Note: \*\*\* represents significance at 1% level

#### 3.5 Johansen Co-integration Test

The results of the Johansen co-integration test are displayed in Table 4. The 5% critical values are used to compare the maximum Eigenvalue statistics and the trace statistics in the test. Since both the maximum Eigenvalue statistics and the trace statistics are greater than the 5% critical values, the test rejects the null hypothesis that there is no co-integrating equation. Nonetheless, because both the maximum Eigenvalue statistics and the trace statistics are less than the 5% critical values, the test accepts the null hypothesis that there is only one co-integrating equation. As a result, the test shows that there is a long-term relationship between GDP, rice imports, and output as well as one co-integrating equation at the 5% level. The long-run relationship can be expressed as follows:

$$\log(\text{GDP}) = 1.0686 \log(\text{Rice Production}) - 1.7676 \log(\text{Rice imports}) \quad (\text{Eq. 14})$$

This equation shows that in the long run, a 1% increase in rice output leads to about 1.1% increase in GDP, while a 1% increase in rice imports leads to about 1.8% decrease in GDP.

Since there is at least one co-integrating relationship among the variables, a granger-causality test can be performed to check if there is any causal relationship among rice output, rice imports, and GDP.

**Table 4. Results of Johansen Co-integration Test**

| Unrestricted Co-Integration Rank Test (Trace Statistics)   |                      |                  |                     |         |
|------------------------------------------------------------|----------------------|------------------|---------------------|---------|
| Hypothesized No. of CE(s)                                  | Eigen Value          | Trace Statistics | 0.05 Critical Value | p-value |
| None *                                                     | 0.482221             | 20.55629         | 15.49471            | 0.0079  |
| At most 1                                                  | 0.049371             | 1.468320         | 3.841466            | 0.2256  |
| Unrestricted Co-integration Rank Test (Maximum Eigenvalue) |                      |                  |                     |         |
| Hypothesized No. of CE(s)                                  | Eigen Value          | Max. Eigenvalue  | 0.05 Critical Value | p-value |
| None ***                                                   | 0.482221             | 19.08797         | 14.26460            | 0.0080  |
| At most 1                                                  | 0.049371             | 1.468320         | 3.841466            | 0.2256  |
| Co-integrating Equation                                    |                      |                  |                     |         |
| Log(GDP)                                                   | Log(Rice Production) |                  | Log (Rice Imports)  |         |
| 1.0000                                                     | - 1.0686<br>(0.4275) |                  | 1.7576<br>(0.4138)  |         |

Note: \*\*\* denotes hypothesis rejection at the 5% level; Values in parenthesis represent standard error

#### 3.6 Pairwise Granger Causality Test

The pairwise Granger causality test result between rice production, rice imports, and GDP is shown in Table 5. The result revealed a significant bidirectional causality between rice production and GDP. This implies that the level of rice production and GDP can be used to predict each other. The result also showed a significant unidirectional relationship ( $p < 0.05$ ) from imports to GDP. This relationship rejects the null hypothesis and thus

implies that rice imports granger cause GDP. This is indicative that GDP of Nigeria is dependent on the level of rice imports. The implication of this is that a reduction in the level of rice imports may improve the GDP of the country. The result further revealed a significant unidirectional relationship ( $p < 0.05$ ) from rice imports to production. Similarly, this relationship rejects the null hypothesis and thus implies that rice imports granger cause rice production. This suggests that rice production in Nigeria is dependent on the level of rice imports. The implication of this is that a reduction in the level of rice imports may increase the rice production level in the country.

**Table 5. Result of Pairwise Granger Causality Test**

| Null hypothesis                             | F-statistics | p-value |
|---------------------------------------------|--------------|---------|
| Production “does not granger cause” GDP     | 3.0492**     | 0.0211  |
| GDP “does not granger cause” production     | 4.1748**     | 0.0183  |
| Imports “does not granger cause” GDP        | 2.8576**     | -0.0118 |
| GDP “does not granger cause” imports        | 2.0031       | 0.7105  |
| Production “does not granger cause” Imports | 0.5565       | 0.6495  |
| Imports “does not granger cause” production | 4.5859**     | 0.0128  |

### 3.7 Determinants of Rice Production and Rice Importation in Nigeria

The result of the simultaneous equation model for factors determining rice production and rice importation in Nigeria is presented in *Table 6*. The  $R^2$  value of 0.5864 indicates that about the explanatory variables account for about 59% variation in the quantity of rice produced in Nigeria. The result showed that rice imports has a negative and significant association ( $p < 0.1$ ) with rice production in Nigeria. This is indicative that a higher rate of rice importation undermines the quantity of rice produced in the country. Population showed a positive and significant association ( $p < 0.05$ ) with the quantity of rice produced in the country. This implies that as population growth increases, rice production also increases. Giyamah-Brempong et al. (2016) in their study identified increasing population growth in Nigeria as one of the major factors stimulating the demand for rice. Schneider et al. (2011) and Ghosh (2021) also opined that population growth increases diversification and food demand, and therefore the demand for agricultural land. Hence, this finding suggests that the increasing population in Nigeria stimulates rice production in the country. On the other hand, the  $R^2$  value of 0.5015 indicates the explanatory variables account for about 50% variation in the quantity of rice imported in Nigeria. Inflation showed a positive and significant association ( $p < 0.1$ ) with rice imports. This implies that as domestic inflation increases, rice importation increases. Inflation increases the price of domestic rice against imported rice which is asserted to be of better quality (Lançon et al., 2004; Onu, 2018), thus stimulating the demand for imported rice in Nigeria. Population also showed a positive and significant association ( $p < 0.1$ ) with rice imports. This result confirms the growing demand for rice imports to offset the increasing rice consumption resulting from increasing population growth rate in Nigeria (Ogazi, 2010; Ayanwale et al., 2011).

**Table 6. Estimates of the Simultaneous Equation Model**

\* and \*\* indicates significance level of 10% and 5% respectively

| Dependent Variables | Explanatory Variables | Coefficients | Std. Error |                |
|---------------------|-----------------------|--------------|------------|----------------|
| Rice production     | Constant              | - 2.5224**   | 7.6873     | $R^2 = 0.5864$ |
|                     | Inflation             | - 0.952821   | 3.475315   |                |
|                     | Rice imports          | - 0.169448*  | 0.103632   |                |
|                     | Exchange rate         | - 0.004099   | 2.064459   |                |
|                     | Population            | 5.9095**     | 2.328186   |                |
| Rice imports        | Constant              | 3.0092       | 8.2290     | $R^2 = 0.5015$ |
|                     | Inflation             | 1.4388 *     | 5.8189     |                |
|                     | Rice production       | -0.172906    | 0.1823     |                |
|                     | Exchange rate         | -5.168259    | 3.5883     |                |
|                     | Population            | 3.1152*      | 7.6133     |                |



#### **4. Conclusions**

The research aimed to investigate the effect of rice importation on rice production and Nigeria's economic growth. The study established that the growth rate of rice imports during the period under investigation is significantly higher than the growth rate of domestic rice production. The government imported rice to meet the increasing demand for rice in Nigeria, which exceeded the domestic production. The significant gap between the growth rate of rice imports and domestic rice production shows over-reliance on rice importation. The magnitude of the long-run relationship between rice importation and GDP revealed that a sustained demand for imported rice has negative financial implications on the economy. The study established a negative and significant unidirectional relationship from imports to GDP, which means that a rise in the level of rice imports may reduce the GDP of the country. Rice importation has a negative and significant relationship with domestic rice production, suggesting that increasing rate rice importation undermines the domestic potential of the Nigerian rice sector. Population growth has a significant and positive relationship with both rice production and rice imports. The increasing population growth of Nigeria suggests a corresponding increase in the demand for imported rice in the near future if no proactive measures are put in place to revamp the Nigerian rice economy. Not only does the growing dependence on rice importation poses a threat to the foreign exchange reserves, a deficit trade account and a negative balance of payments are also possible implications. Adopting a multifaceted policy measure or strategy that emphasizes reducing rice importation, increasing domestic production of rice, and enhancing the standard of living for domestic rice producers is a key policy objective.

#### **Ethical Statement**

There was no need to obtain permission from the ethics committee for this study.

#### **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

#### **Authorship Contribution Statement**

Concept: Akinsola, G. O., Bello, M. A., Bello, W. O; Design: Akinsola, G. O., Osasona, K. K., Bello, M. A.; Data Collection or Processing: Bello, M. A., Bello, W. O; Statistical Analysis: Osasona, K. K., Bello, M. A; Literature Search: Osasona, K.K., Bello, M. A., Bello, W. O; Writing, Review and Editing: Akinsola, G. O., Osasona, K. K., Bello, M. A.

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**Reciprocal Effect and Inbreeding Depression in Advanced Generations of Cotton  
(*Gossypium hirsutum* L.) Bulk Population**

Pamukta İleri Bulk Populasyon Hatlarında Kendileme Depresyonu ve Resiprokal Etki

Şerife BALCI<sup>1</sup>, Volkan Mehmet ÇINAR<sup>2</sup>, Aydın ÜNAY<sup>3\*</sup>**Abstract**

Reciprocal differences reflect an unequal contribution of male and female parents in plant breeding. We investigated the reciprocal differences, inbreeding depression, and performance of bulk populations in advanced generations. Seven hybrid combinations and their reciprocals were evaluated in F<sub>4</sub> and F<sub>5</sub> generations in a Randomized Complete Block Design with three replications. The significant reciprocal differences in many combinations for seed cotton yield and fiber length in both generations indicated the importance of selecting parents as male or female at the start of breeding work for these traits. In contrast, fiber fineness, fiber strength, and ginning out-turn were generally traits for which the reciprocal differences of the lines were not significant. The difference in general averages of F<sub>4</sub> and F<sub>5</sub> generations was significant regarding fiber length and fineness. Advanced lines in the F<sub>5</sub> generation were found to have longer and finer fibers. In F<sub>4</sub> generation lines, seed cotton yield per plant ranged between 100.30-160.87 g; ginning out-turn 41.96-47.17%; fiber length 30.04-32.94 mm; fiber fineness 4.52-5.11 mic. and fiber strength 32.50-34.60 g tex<sup>-1</sup>, while these values were 101.11-137.63 g; 41.45-46.54%; 30.55-33.09 mm; 4.24-4.90 mic. and 32.03-34.30 g tex<sup>-1</sup> in F<sub>5</sub> generation, respectively. The higher inbreeding depression estimates for seed cotton yield indicated that non-additive genes were more predominant in the inheritance of this trait compared to ginning out-turn and fiber quality parameters. As a result of the study, it was concluded that it would be beneficial to transfer Carmen × Carisma, Flash × Claudia, and ST-468 × Claudia F<sub>5</sub> advanced lines, which showed superior performance in terms of seed cotton yield and fiber properties, to the F<sub>6</sub> generation.

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## Öz

Bitki ıslahında geliştirilen melezlerde ana ve baba olarak kullanılan anaçların eşit olmayan katkıları resiprokal farklılıklar olarak tanımlanmaktadır. Bu çalışmayı ileri pamuk generasyonlarında farklı bulk popülasyonlarının performansını, kendileme depresyonunu ve resiprokal farklılıkları incelemek amacıyla yürüttük. F<sub>4</sub> ve F<sub>5</sub> generasyonlarında yer alan 7 farklı melez kombinasyonunu resiprokal melezleri ile birlikte Tesadüf Blokları Deneme Deseninde üç tekerrürlü olarak değerlendirdik. Kütlü pamuk verimi ve lif uzunluğu için her iki generasyonda yer alan çok sayıda kombinasyonda resiprokal farklılıkların önemli olması, bu özellikler için ıslah çalışmasının başlangıcında anaçların ana veya baba olarak kullanılmasının önemini göstermektedir. Buna karşın lif inceliği, lif dayanıklılığı ve çırcır randımanı yönünden ise hatların çoğunluğunda resiprokal farklılıkların önemli olmadığı tespit edildi. F<sub>4</sub> ve F<sub>5</sub> generasyonlarına ilişkin genel ortalamalarının farkı lif uzunluğu ve lif inceliği yönünden önemli bulundu. F<sub>5</sub> generasyonundaki hatların daha uzun ve daha ince liflere sahip olduğu saptandı. Bunlara ek olarak, F<sub>4</sub> generasyonu hatlarında tek bitki kütlü pamuk verimi 100,30-160,87 g; çırcır randımanı %41,96-47,17; lif uzunluğu 30,04-32,94 mm; lif inceliği 4,52-5,11 mic. ve lif dayanıklılığı 32,50-34,60 g tex<sup>-1</sup> arasında değişirken, F<sub>5</sub> generasyonunda tek bitki kütlü verimi 101,11-137,63 g; çırcır randımanı %41,45-46,54; lif uzunluğu 30,55-33,09 mm; lif inceliği 4,24-4,90 mic. ve lif dayanıklılığı ise 32,03-34,30 g tex<sup>-1</sup> arasında değişmiştir. Kütlü pamuk verimi için bulunan daha yüksek kendileme depresyonu çırcır randımanı ve lif kalite özelliklerine kıyasla bu özelliğin kontrolünde eklemeli olmayan gen etkilerinin daha baskın olduğunun bir göstergesiydi. Çalışma sonucunda, kütlü pamuk verimi ve lif özellikleri yönünden üstün performans gösteren Carmen × Carisma, Flash × Claudia ve ST-468 × Claudia F<sub>5</sub> ileri hatlarının F<sub>6</sub> generasyonuna aktarılmasının yararlı olacağı kanısına varıldı.

**Anahtar Kelimeler:** Atasal kalıtım, F<sub>4</sub> ve F<sub>5</sub>, Lif kalitesi, Kütlü pamuk verimi, Seleksiyon

## 1. Introduction

Türkiye is a leading cotton producer (Ağazade, 2021). The most important fiber crop, cotton (*Gossypium hirsutum* L.), is cultivated in a total area of 500 thousand ha in the Southeastern Anatolia, Aegean, and Mediterranean regions of Türkiye. Cotton is extensively used in the textile industry and oil sector, and its cottonseed meal is also utilized in animal nutrition. Environmental factors, crop management, and genetic factors affected the seed cotton yield and quality parameters (Xiao and Tao, 2014; Rizzo et al., 2022). Plant breeders constantly try to develop new cotton varieties with higher yields and quality (Bilgin and Korkut, 2005). Choosing a suitable parent in the cotton breeding program is one of the most important processes (Lukonge et al., 2008). In other words, many crosses are required to determine suitable parents based on progeny performance in cotton, as in all cultivated plants. The mean performance is the primary criterion for choosing better hybrids because it exposes their real value.

The reciprocal effect, cytoplasmic effects, and parent-of-origin effect are epigenetic phenomena, and they are defined as the difference between the hybrid performance obtained when classical hybrids and parents are replaced. Thus, the choice of which parent will be used as male or female in breeding studies is determined. Numerous genetic factors influence reciprocal differences, perhaps the most important of which is that two sets of chromosomes of the endosperm, which contains three sets of chromosomes, come from the maternal parent (Gonzalo et al., 2007). Moreover, non-allelic reciprocal effects were reported to lead to invalidation of the additive-dominant model (Abedi et al., 2015).

In studies on cotton, the results of the full diallel analysis indicated different reciprocal effects in terms of significance. Shaukat et al. (2013) emphasized significant specific combining ability effects and reciprocal effects for fiber fineness, length, and strength, whereas non-significant reciprocal effects for the said traits were recorded by Hussain et al. (2010). Non-significant differences between reciprocal crosses in the F<sub>1</sub> and F<sub>2</sub> generations were recorded for yield, yield components, and fiber quality parameters, whereas significant reciprocal differences were detected in the F<sub>3</sub> generation by Zhang et al. (2016). Similarly, it was stated that the effects of combining ability for boll number per sympodial branch and plant, boll weight, ginning out-turn, and seed cotton yield differ in reciprocal crosses (Khan et al., 2015). It was emphasized that using elite cultivars as female parents had higher performance than their reciprocals because direct cross hybrids outperformed their respective reciprocal crosses for most of the traits evaluated (AnandaLekshmi et al., 2023).

Studies on the reciprocal effect have concentrated on early generations. However, more accurate predictions can be achieved in later generations when homozygosity and homogeneity increase. In addition, in cases where reciprocal lines are used, their performance in later generations is unknown. Therefore, we tested the hypothesis that the reciprocal effect decreases in advanced generations to determine whether the reciprocal effect is important not only in hybrid cultivar breeding and pedigree and bulk breeding processes. For this purpose, we evaluated seven advanced lines and their reciprocals in F<sub>4</sub> and F<sub>5</sub> bulk population generations regarding fiber properties and yield.

## 2. Materials and Methods

The initial material of the study was developed by crossing seven cotton (*Gossypium hirsutum* L.) varieties (Gloria, Claudia, Carmen, Julia, ST-468, Carisma, and Flash) according to the reciprocal line × tester method (4 × 3 and versus) at Cotton Research Institute, Nazilli-Aydın. F<sub>4</sub> bulk populations were developed from selected seven cross combinations and their reciprocals. Half of the seeds of the F<sub>4</sub> populations were saved for the following year. In 2020, F<sub>4</sub> and F<sub>5</sub> bulk populations were grown in a Randomized Complete Block Design with three replications.

The soil structure of the trial field is slightly alkaline and non-saline, with very high lime content, high nitrogen content, medium phosphorus levels, and low potassium levels. According to climatic data in 2020, the highest maximum daily temperatures were recorded in July (39.7 °C) and August (39.1 °C). May and October had the lowest minimum daily temperatures (14.7 and 14.3 °C, respectively). The average daily temperatures varied from 20.6 °C (October) to 28.9 °C (July), and the average monthly rainfall was below 1.0 mm.

Plots comprised six 12-m-long rows with a 70 × 20 cm sowing norm. Agricultural practices such as fertilization, weed control, irrigation, and insect control were standard practices for the Aegean Region, Türkiye. We observed 20 competitive plants to detect biometrical traits, seed cotton yield per plant (g), ginning out-turn (%), and fiber quality parameters for each genotype at each plot. Fiber fineness (mic.), fiber length (mm), and fiber strength (g tex<sup>-1</sup>) were also determined using Uster® HVI-1000 at the fiber quality laboratory at Nazilli Cotton Research Institute.

The observed data were subjected to analysis of variance (Steel et al., 1997) using the ‘agricolae’ package (Mendiburu and Mendiburu 2019) in R software. The least significant difference (LSD) test and orthogonal contrast technique were used to separate genotype and generation means, respectively. Reciprocal cross advantages (R) were calculated according to the formula proposed by Bulant et al. (2000);

$$R (\%) = \frac{\text{Normal cross mean} - \text{Reciprocal cross mean}}{\text{Normal cross mean}} \times 100 \quad (\text{Eq.1}).$$

Inbreeding depression and critical value for significance were calculated according to the following method (Singh, 2003);

$$\text{Inbreeding depression} (\%) = \frac{F_4 - F_5}{F_4} \times 100 \quad (\text{Eq.2}).$$

$$\text{Critical Value} = \frac{\sqrt{2MSE}}{r} \times 5\% \text{ and } 1\% \text{ t table value.} \quad (\text{Eq.3}).$$

where; MSE is the mean square for error and r is the number of replications.

### 3. Results

The significant reciprocal effects for seed cotton yield were recorded in Carmen × Carisma, Carmen × Flash, Flash × Gloria, and Carisma × Julia in both generations (*Table 1*). The difference between the grand means of the F<sub>4</sub> and F<sub>5</sub> populations was non-significant. Carmen × Carisma in F<sub>4</sub>; Carmen × Carisma and ST-468 × Claudia in F<sub>5</sub> produced the highest seed cotton yield. The negative and significant inbreeding depression was observed in Carmen × Carisma and its reciprocal and Gloria × Flash, whereas F<sub>5</sub> lines of Flash × Carmen, Flash × Claudia and its reciprocal, Julia × ST-468 and ST-468 × Claudia had higher performance than that of F<sub>4</sub> lines (*Table 1*).

**Table 1. Reciprocal differences, mean value, and inbreeding depression for seed cotton yield.**

| Genotype                         | Reciprocal | Reciprocal Advantage (%) F <sub>4</sub> | Reciprocal Advantage (%) F <sub>5</sub> | Seed Cotton Yield (g) |                | Inbreeding Depression |
|----------------------------------|------------|-----------------------------------------|-----------------------------------------|-----------------------|----------------|-----------------------|
|                                  |            |                                         |                                         | F <sub>4</sub>        | F <sub>5</sub> |                       |
| Carmen × Carisma                 | A × B      | -20.60**                                | -20.43**                                | 160.87                | 137.63         | 14.44**               |
| Carisma × Carmen                 | B × A      |                                         |                                         | 127.73                | 109.52         | 14.26*                |
| Carmen × Flash                   | A × B      | -19.65**                                | -17.66*                                 | 124.83                | 122.79         | 1.63                  |
| Flash × Carmen                   | B × A      |                                         |                                         | 100.30                | 101.11         | -0.81                 |
| Flash × Gloria                   | A × B      | 26.70**                                 | 18.97*                                  | 109.87                | 103.75         | 5.57                  |
| Gloria × Flash                   | B × A      |                                         |                                         | 139.20                | 123.44         | 11.32*                |
| Flash × Claudia                  | A × B      | -4.14                                   | -2.98                                   | 112.03                | 130.14         | -16.16*               |
| Claudia × Flash                  | B × A      |                                         |                                         | 107.40                | 126.27         | -17.57*               |
| Carisma × Julia                  | A × B      | 16.80*                                  | 24.18**                                 | 106.77                | 103.55         | 3.01                  |
| Julia × Carisma                  | B × A      |                                         |                                         | 124.70                | 128.59         | -3.12                 |
| ST-468 × Julia                   | A × B      | 6.93                                    | 1.93                                    | 111.13                | 104.57         | 5.90                  |
| Julia × ST-468                   | B × A      |                                         |                                         | 118.83                | 106.59         | -10.30*               |
| ST-468 × Claudia                 | A × B      | 2.85                                    | -3.73                                   | 118.23                | 136.40         | -15.36*               |
| Claudia × ST-468                 | B × A      |                                         |                                         | 121.60                | 131.31         | -7.99                 |
| <b>Mean</b>                      |            |                                         |                                         | <b>120.25</b>         | <b>125.41</b>  | <b>-5.33</b>          |
| LSD (0.05)                       |            |                                         |                                         | 16.70                 | 13.89          |                       |
| F <sub>4</sub> vs F <sub>5</sub> |            |                                         |                                         | ns                    |                |                       |

\*, \*\*, significant at 5% and 1% probability level, respectively. ns: non-significant.



Ginning out-turn values of ST-468 × Claudia, Flash × Claudia, and their reciprocals significantly differed in both generations (Table 2). The grand mean of the F<sub>4</sub> generation was significantly superior to F<sub>5</sub>. Flash × Claudia in F<sub>4</sub> and ST-468 × Claudia lines in both generations had the higher ginning out-turn. Gloria × Flash, Flash × Claudia, Carisma × Julia, and Claudia × ST-468 exhibited negative and significant inbreeding depression.

**Table 2. Reciprocal differences, mean value, and inbreeding depression for ginning out-turn.**

| Genotype                         | Reciprocal | Reciprocal Advantage (%) F <sub>4</sub> | Reciprocal Advantage (%) F <sub>5</sub> | Ginning out-turn (%) |                | Inbreeding Depression |
|----------------------------------|------------|-----------------------------------------|-----------------------------------------|----------------------|----------------|-----------------------|
|                                  |            |                                         |                                         | F <sub>4</sub>       | F <sub>5</sub> |                       |
| Carmen × Carisma                 | A × B      | 1.48                                    | -0.71                                   | 43.95                | 44.18          | -0.51                 |
| Carisma × Carmen                 | B × A      |                                         |                                         | 43.43                | 43.86          | -0.99                 |
| Carmen × Flash                   | A × B      | 1.45                                    | 2.39                                    | 41.96                | 42.18          | -0.52                 |
| Flash × Carmen                   | B × A      |                                         |                                         | 42.57                | 43.19          | -1.46                 |
| Flash × Gloria                   | A × B      | 2.63                                    | -0.45                                   | 42.12                | 41.98          | 0.32                  |
| Gloria × Flash                   | B × A      |                                         |                                         | 43.23                | 41.79          | 3.32*                 |
| Flash × Claudia                  | A × B      | -7.11**                                 | -5.25**                                 | 47.17                | 45.12          | 4.34**                |
| Claudia × Flash                  | B × A      |                                         |                                         | 43.81                | 42.75          | 2.43                  |
| Carisma × Julia                  | A × B      | -3.43                                   | -3.75                                   | 44.72                | 43.06          | 3.71*                 |
| Julia × Carisma                  | B × A      |                                         |                                         | 43.19                | 41.45          | 4.03*                 |
| ST-468 × Julia                   | A × B      | 1.11                                    | 0.54                                    | 43.84                | 44.24          | -0.90                 |
| Julia × ST-468                   | B × A      |                                         |                                         | 44.33                | 44.48          | -0.34                 |
| ST-468 × Claudia                 | A × B      | -6.18**                                 | -9.28**                                 | 46.97                | 46.54          | 0.92                  |
| Claudia × ST-468                 | B × A      |                                         |                                         | 44.07                | 42.22          | 4.19**                |
| <b>Mean</b>                      |            |                                         |                                         | <b>44.17</b>         | <b>43.36</b>   | <b>2.27</b>           |
| LSD <sub>(0.05)</sub>            |            |                                         |                                         | 1.97                 | 1.72           |                       |
| F <sub>4</sub> vs F <sub>5</sub> |            |                                         |                                         | ns                   |                |                       |

\*, \*\*, significant at 5% and 1% probability level, respectively. ns: non-significant.

**Table 3. Reciprocal differences, mean value, and inbreeding depression for fiber length**

| Genotype                         | Reciprocal | Reciprocal Advantage (%) F <sub>4</sub> | Reciprocal Advantage (%) F <sub>5</sub> | Fiber Length (mm) |                | Inbreeding Depression |
|----------------------------------|------------|-----------------------------------------|-----------------------------------------|-------------------|----------------|-----------------------|
|                                  |            |                                         |                                         | F <sub>4</sub>    | F <sub>5</sub> |                       |
| Carmen × Carisma                 | A × B      | 2.12 <sup>ns</sup>                      | 1.60 <sup>ns</sup>                      | 30.59             | 31.18          | -1.92                 |
| Carisma × Carmen                 | B × A      |                                         |                                         | 31.24             | 31.68          | -1.40                 |
| Carmen × Flash                   | A × B      | -0.64 <sup>ns</sup>                     | 1.69 <sup>ns</sup>                      | 30.96             | 31.23          | -0.88                 |
| Flash × Carmen                   | B × A      |                                         |                                         | 30.76             | 31.76          | -3.24                 |
| Flash × Gloria                   | A × B      | -5.60**                                 | -4.76**                                 | 31.83             | 32.13          | -0.96                 |
| Gloria × Flash                   | B × A      |                                         |                                         | 30.04             | 30.60          | -5.19**               |
| Flash × Claudia                  | A × B      | 4.87**                                  | 4.31*                                   | 30.61             | 31.28          | -2.18                 |
| Claudia × Flash                  | B × A      |                                         |                                         | 32.10             | 32.62          | -1.63                 |
| Carisma × Julia                  | A × B      | -3.70*                                  | -6.57**                                 | 32.38             | 33.09          | -2.19                 |
| Julia × Carisma                  | B × A      |                                         |                                         | 30.22             | 30.91          | -2.29                 |
| ST-468 × Julia                   | A × B      | 4.54**                                  | 4.42*                                   | 29.87             | 30.55          | -2.29                 |
| Julia × ST-468                   | B × A      |                                         |                                         | 31.22             | 31.90          | -2.17                 |
| ST-468 × Claudia                 | A × B      | 4.79**                                  | 3.29*                                   | 31.43             | 31.12          | 1.00                  |
| Claudia × ST-468                 | B × A      |                                         |                                         | 32.94             | 32.14          | 2.42                  |
| <b>Mean</b>                      |            |                                         |                                         | <b>31.09</b>      | <b>31.66</b>   | <b>-1.87</b>          |
| LSD <sub>(0.05)</sub>            |            |                                         |                                         | 0.99              | 1.01           |                       |
| F <sub>4</sub> vs F <sub>5</sub> |            |                                         |                                         | **                |                |                       |

\*, \*\*, significant at 5% and 1% probability level, respectively. ns: non-significant.

**Table 4. Reciprocal differences, mean value and inbreeding depression for fiber fineness.**

| Genotype                         | Reciprocal | Reciprocal Advantage (%) F <sub>4</sub> | Reciprocal Advantage (%) F <sub>5</sub> | Fiber Fineness (mic.) |                | Inbreeding Depression |
|----------------------------------|------------|-----------------------------------------|-----------------------------------------|-----------------------|----------------|-----------------------|
|                                  |            |                                         |                                         | F <sub>4</sub>        | F <sub>5</sub> |                       |
| Carmen × Carisma                 | A × B      | 6.73*                                   | 3.46 <sup>ns</sup>                      | 4.70                  | 4.43           | 5.74*                 |
| Carisma × Carmen                 | B × A      |                                         |                                         | 5.02                  | 4.59           | 8.63**                |
| Carmen × Flash                   | A × B      | -1.37 <sup>ns</sup>                     | -5.82*                                  | 5.11                  | 4.76           | 6.98**                |
| Flash × Carmen                   | B × A      |                                         |                                         | 5.04                  | 4.48           | 11.17**               |
| Flash × Gloria                   | A × B      | 0.35 <sup>ns</sup>                      | 1.11 <sup>ns</sup>                      | 4.74                  | 4.49           | 5.14*                 |
| Gloria × Flash                   | B × A      |                                         |                                         | 4.75                  | 4.54           | 4.42                  |
| Flash × Claudia                  | A × B      | -6.06*                                  | -8.51**                                 | 4.95                  | 4.90           | 1.14                  |
| Claudia × Flash                  | B × A      |                                         |                                         | 4.65                  | 4.48           | 3.72                  |
| Carisma × Julia                  | A × B      | -4.84 <sup>ns</sup>                     | 4.71 <sup>ns</sup>                      | 4.75                  | 4.46           | 6.04*                 |
| Julia × Carisma                  | B × A      |                                         |                                         | 4.52                  | 4.67           | -3.39                 |
| ST-468 × Julia                   | A × B      | 2.41 <sup>ns</sup>                      | -1.55 <sup>ns</sup>                     | 4.57                  | 4.31           | 5.69*                 |
| Julia × ST-468                   | B × A      |                                         |                                         | 4.68                  | 4.24           | 9.33**                |
| ST-468 × Claudia                 | A × B      | -0.89 <sup>ns</sup>                     | 2.84 <sup>ns</sup>                      | 4.87                  | 4.46           | 8.29**                |
| Claudia × ST-468                 | B × A      |                                         |                                         | 4.82                  | 4.59           | 4.84                  |
| <b>Mean</b>                      |            |                                         |                                         | <b>4.80</b>           | <b>4.53</b>    | <b>5.55</b>           |
| LSD (0.05)                       |            |                                         |                                         | 0.27                  | 0.21           |                       |
| F <sub>4</sub> vs F <sub>5</sub> |            |                                         |                                         |                       | **             |                       |

\*, \*\*, significant at 5% and 1% probability level, respectively. ns: non-significant.

**Table 5. Reciprocal differences, mean value, and inbreeding depression for fiber strength.**

| Genotype                         | Reciprocal | Reciprocal Advantage (%) F <sub>4</sub> | Reciprocal Advantage (%) F <sub>5</sub> | Fiber Strength (g tex <sup>-1</sup> ) |                | Inbreeding Depression |
|----------------------------------|------------|-----------------------------------------|-----------------------------------------|---------------------------------------|----------------|-----------------------|
|                                  |            |                                         |                                         | F <sub>4</sub>                        | F <sub>5</sub> |                       |
| Carmen × Carisma                 | A × B      | -2.70 <sup>ns</sup>                     | 4.58 <sup>ns</sup>                      | 33.65                                 | 32.03          | 4.79                  |
| Carisma × Carmen                 | B × A      |                                         |                                         | 32.74                                 | 33.50          | -2.33                 |
| Carmen × Flash                   | A × B      | 1.25 <sup>ns</sup>                      | 3.63 <sup>ns</sup>                      | 34.17                                 | 33.10          | 3.13                  |
| Flash × Carmen                   | B × A      |                                         |                                         | 34.60                                 | 34.30          | 0.86                  |
| Flash × Gloria                   | A × B      | -1.12                                   | -3.72                                   | 33.10                                 | 34.07          | -2.93                 |
| Gloria × Flash                   | B × A      |                                         |                                         | 32.73                                 | 32.80          | -3.59                 |
| Flash × Claudia                  | A × B      | 2.64 <sup>ns</sup>                      | 3.83 <sup>ns</sup>                      | 32.67                                 | 32.20          | 1.45                  |
| Claudia × Flash                  | B × A      |                                         |                                         | 33.54                                 | 33.43          | 0.31                  |
| Carisma × Julia                  | A × B      | 2.72 <sup>ns</sup>                      | -3.05 <sup>ns</sup>                     | 33.64                                 | 33.53          | 0.32                  |
| Julia × Carisma                  | B × A      |                                         |                                         | 32.50                                 | 32.51          | -0.02                 |
| ST-468 × Julia                   | A × B      | 0.20 <sup>ns</sup>                      | 1.30 <sup>ns</sup>                      | 33.29                                 | 33.23          | 0.17                  |
| Julia × ST-468                   | B × A      |                                         |                                         | 33.36                                 | 33.67          | -0.93                 |
| ST-468 × Claudia                 | A × B      | 1.78 <sup>ns</sup>                      | 4.08 <sup>ns</sup>                      | 33.83                                 | 32.67          | 3.44                  |
| Claudia × ST-468                 | B × A      |                                         |                                         | 34.43                                 | 34.00          | 1.26                  |
| <b>Mean</b>                      |            |                                         |                                         | <b>33.44</b>                          | <b>33.20</b>   | <b>0.59</b>           |
| LSD (0.05)                       |            |                                         |                                         | 1.70                                  | 1.71           |                       |
| F <sub>4</sub> vs F <sub>5</sub> |            |                                         |                                         |                                       | ns             |                       |

\*, \*\*, significant at 5% and 1% probability level, respectively. ns: non-significant.

The reciprocal differences of ST-468 × Claudia, ST-468 × Julia, Carisma × Julia, and Flash × Claudia in both generations and Flash × Gloria in F<sub>4</sub> were significant for fiber length (Table 3). It was shown that the F<sub>5</sub> bulk populations produced higher fiber lengths than those of the F<sub>4</sub>. This was generally reflected positively in inbreeding depression, except for ST-468 × Claudia and its reciprocal.

Flash × Claudia in both generations, Carmen × Carisma in F<sub>4</sub>, and Carmen × Flash in F<sub>5</sub> differed from the reciprocals for fiber fineness (Table 4). The difference between the grand mean of the generations was significant.

Julia  $\times$  Carisma and ST-468  $\times$  Julia in F<sub>4</sub>, ST-468  $\times$  Julia and its reciprocal in F<sub>5</sub> had positive performance. The generally positive and significant inbreeding depression indicated that F<sub>5</sub> bulk populations exhibited finer fibers.

The reciprocal differences of all bulk populations in both generations were non-significant for fiber strength (Table 5). The grand mean of F<sub>4</sub> and F<sub>5</sub> lines were similar, whereas Julia  $\times$  Carisma, Flash  $\times$  Claudia, Gloria  $\times$  Flash, and Carisma  $\times$  Carmen in F<sub>4</sub>; Carmen  $\times$  Carisma and Flash  $\times$  Claudia in F<sub>5</sub> had significantly lower fiber strength than that of other lines. Non-significant inbreeding depression values indicated that the fiber strength of F<sub>5</sub> lines was unchanged.

#### 4. Discussion

Most hybrid combinations showing reciprocal significance were recorded in fiber length and seed cotton yield, whereas fiber strength was the character for which there was no reciprocal difference. The fact that the reciprocal differences for seed cotton yield and fiber length in cross combinations were significant in both generations gives the impression that the reciprocal differences will not change from generation to generation. In parallel with our study results, Khan et al. (2009) and Zangi et al. (2010) pronounced the reciprocal differences for yield and yield components, whereas significant reciprocal effects for days to flowering, seeds/locule, and lint percentage (Khan et al., 2011) and fiber fineness (Wells and Meredith, 1984) were estimated in an earlier generation.

The grand mean of F<sub>4</sub> and F<sub>5</sub> for observed characters indicated that seed cotton yield, ginning out-turn, and fiber strength remained stable, while the F<sub>5</sub> bulk population had significantly finer and longer fiber. This showed that the breeding program carried out was generally successful. According to Uster cotton classification, fibers between 4.0 and 4.9 mic.; 29.5 and 32.5 mm; and above 30.0 g tex<sup>-1</sup> are defined as average, long, and strong, respectively (USTER, 2024). The fiber properties of all F<sub>5</sub> bulk populations in our study meet these standards. Carmen  $\times$  Carisma, Flash  $\times$  Claudia, and ST-468  $\times$  Claudia combinations were also performed for seed cotton yield and ginning out-turn.

Ginning out-turn and fiber quality characteristics compared to yield presented lower inbreeding depression, corroborating the results reported by Khan et al. (2007), Khan et al. (2009), and Tigga et al. (2017). The high inbreeding depression for seed cotton yield indicated that dominance persists even in advanced generations such as F<sub>5</sub> (Carvalho et al., 2018). The combinations such as Carmen  $\times$  Carisma, Flash  $\times$  Claudia, and ST-468  $\times$  Claudia with high performance in terms of yield showed high and significant inbreeding depression. It was concluded that continuing the bulk selection method would be useful, especially in these combinations.

#### 5. Conclusions

It is concluded that reciprocal differences persist in advanced generations. For this reason, at the beginning of the breeding program, selecting suitable parents and determining whether they will be used as males or females would be useful. The higher inbreeding depression for seed cotton yield indicates continued dominance compared with other traits. It was concluded that Carmen  $\times$  Carisma, Flash  $\times$  Claudia, and ST-468  $\times$  Claudia F<sub>5</sub> lines should be transferred to the F<sub>6</sub> generation. The fact that the negative associations between yield and ginning out-turn and fiber quality characteristics found in other combinations were broken in these three combinations shows the success of suitable parent selection.

#### Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

#### Conflicts of Interest

We declare no conflict of interest between us as the article authors.

#### Authorship Contribution Statement

Concept: Ünay, A.; Design: Balcı, Ş., Ünay, A.; Data Collection or Processing: Balcı, Ş.; Statistical Analyses: Çınar, V.M.; Literature Search: Çınar, V.M., Ünay, A.; Writing, Review and Editing: Balcı, Ş., Çınar, V.M., Ünay, A.

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**Mathematical Modelling of Galactooligosaccharides Synthesis: Insights into *Aspergillus oryzae* Derived  $\beta$ -Galactosidase Kinetics\***

Galaktooligosakkarit Sentezinin Matematiksel Modellenmesi: *Aspergillus oryzae* kaynaklı  $\beta$ -Galaktosidaz Kinetiğine İlişkin Bilgiler

Kadir CINAR<sup>1\*</sup>, Hacı Ali GULEC<sup>2</sup>, Gurbuz GUNES<sup>3</sup>

**Abstract**

The objective of this study was to adapt experimental data with a mathematical model based on transgalactosylation mechanisms identified in the literature for the synthesis of galactooligosaccharides and lactose hydrolysis. Galactooligosaccharides, synthesized from lactose through  $\beta$ -galactosidase-catalyzed transgalactosylation reactions, are acknowledged as specific bifidogenic factors among prebiotic carbohydrates. Modelling galactooligosaccharide synthesis is challenging due to simultaneous hydrolysis and transferase reactions with identical nucleophiles and substrates. Therefore, researchers tried to simplify the mechanism by ignoring intermediate reactions or inhibitory effects of glucose and galactose. This study explored various kinetic models, considering the complexity of the reaction mechanism and balancing accuracy with feasibility. Experimental data from galactooligosaccharide synthesis using a continuous stirred tank reactor was adapted to kinetic models (Models A and B) with modifications, incorporating glucose and galactose inhibitions. The COPASI software was used for testing fitness of reaction models. Eight models were evaluated for their suitability, utilizing six replicated experimental datasets under specific reaction conditions, including a temperature of 45°C, lactose concentration of 18.25°Brix, and enzyme concentration of 10-unit g lactose solution<sup>-1</sup>. The analysis was conducted using the "random research" and "particle swarm" algorithms. Model evaluations revealed that Model B, augmented with glucose and galactose inhibitions, provided the closest alignment between experimental and simulated data. The study underscored the significance of glucose and galactose impacts on galactooligosaccharide synthesis efficiency. The Model B, with addition of glucose and galactose inhibitions, emerged as a valuable tool for predicting galactooligosaccharide yield, contributing to a deeper understanding of *A.oryzae*-derived  $\beta$ -galactosidase kinetics due to its significant influence on parameters such as productivity, conversion of lactose, and composition of product. The findings will guide optimization strategies for enhanced galactooligosaccharide production efficiency, advancing knowledge in enzymatic galactooligosaccharide synthesis.

**Keywords:** Kinetics, Transgalactosylation, Hydrolysis, Galactooligosaccharides, *A. oryzae*

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## Öz

Bu çalışmanın amacı, elde edilen deneysel verileri literatürde tanımlanmış laktoz hidrolizi ve galaktooligosakkaritlerin sentezi için belirlenmiş transgalaktosilasyon mekanizmalarına dayalı matematiksel bir modele uyumlu hale getirmektir. Galaktooligosakkaritler, laktozun  $\beta$ -galaktosidaz katalizli transgalaktosilasyon reaksiyonları aracılığıyla sentezlenen özel bifidojenik faktörler olarak bilinirler. Galaktooligosakkarit sentez mekanizmasının, aynı nükleofillere ve substratlara sahip hidroliz ve transferaz reaksiyonlarının eş zamanlı olarak gerçekleşmesi nedeniyle matematiksel modellemesi zorluklar içermektedir. Bu nedenle araştırmacılar, meydana gelen ara reaksiyonları veya glukoz ve galaktozun inhibe edici etkilerini göz ardı ederek mekanizmayı basitleştirmeye çalıştılar. Bu çalışma, reaksiyon mekanizmasının karmaşıklığını göz önünde bulundurarak doğruluk ile uygulanabilirlik arasında denge sağlamak amacıyla çeşitli kinetik modellerin uygunluğunu değerlendirmektedir. Sürekli karıştırılmalı tank reaktörü kullanılarak elde edilen deneysel veriler, glukoz ve galaktoz inhibitörlerini içeren modifikasyonlarla kinetik modellere (Model A ve B) adapte edilmiştir. COPASI yazılımı, model denklemleri test etmek amacıyla kullanılmıştır. Toplam 8 adet model, 6 tekrarlı deneysel veri setinde (sıcaklık:45°C, laktoz konsantrasyonu:18.25 Briks ve enzim konsantrasyonu:10 ünite g laktoz çözeltisi<sup>-1</sup>) uygunluğu test edilmiştir. Çözümleme sırasıyla “random research” ve “particle swarm” algoritmaları kullanılarak gerçekleştirilmiştir. Model değerlendirmeleri, glukoz ve galaktoz inhibitörlerini içeren Model B'nin deneysel ve simüle veriler arasında en yakın uyumu sağladığını göstermiştir. Çalışma, glukoz ve galaktozun galaktooligosakkarit sentezi verimliliği üzerindeki inhibitör etkilerinin önemini ortaya koymuştur. Glukoz ve galaktoz inhibitörlerini içeren Model B, galaktooligosakkarit veriminin öngörülmesi ve laktoz dönüşümü, üretkenlik, ürün bileşimi gibi parametreler üzerindeki önemli etkisi nedeniyle *A. oryzae* kaynaklı  $\beta$ -galaktosidaz kinetiğinin daha iyi anlaşılmasına katkı sağlayacak önemli bir araçtır. Çalışma sonucunda elde edilen bulgular, galaktooligosakkarit üretim verimliliğini artırmak için optimizasyon stratejilerine rehberlik edecek ve enzimatik galaktooligosakkarit sentezi konusunda literatüre katkı sağlayacaktır.

**Anahtar Kelimeler:** Kinetik, Transgalaktosilasyon, Hidroliz, Galaktooligosakkaritler, *A. oryzae*



## 1. Introduction

Galactooligosaccharides (GOS) are recognized as the most specific bifidogenic components among prebiotic carbohydrates (Uran et al., 2021). They are produced from lactose through transgalactosylation reactions facilitated by  $\beta$ -galactosidases. Various studies have been conducted in the literature to model the synthesis mechanism of GOS using different approaches (Chen et al., 2003; Mueller et al., 2018). The GOS synthesis mechanism is a complex process due to its simultaneous hydrolysis and transferase reactions, resulting from having identical nucleophiles and substrates. Consequently, evaluating the apparent rate constants is challenging. Researchers studying the GOS synthesis mechanism initially suggest a reaction pathway, allocating rate constants to each stage during catalysis, which are then experimentally determined. The comprehensive understanding of the reaction mechanism of  $\beta$ -galactosidase in existing literature adds attractiveness to this approach. Simplifications are made in the reaction mechanism to limit the number of experimentally predicted rate constants. While excessive simplifications negatively impact the model's accuracy, they may render the model construction more appropriate. Hence, achieving a balance between model accuracy and feasibility is crucial. Due to numerous unknown kinetic parameters, some authors have attempted to simplify the reaction mechanism by eliminating glucose (Vera et al., 2011) and galactose (Mueller et al., 2018) inhibition or both for reactions catalyzed by  $\beta$ -galactosidase from *A. oryzae*.

Iwasaki et al. (1996) expressed that the simultaneous occurrence of hydrolysis and transferase reactions in enzymatic GOS synthesis complicates the mathematical analysis. Therefore, they assumed that the GOS synthesis reaction could be represented by a stoichiometrically simple model. They constructed a GOS synthesis reaction model with a biochemical reaction chain consisting of thirteen equations, incorporating the formation of 3 and 4-chain GOS (GOS-3 and GOS-4, respectively) in their model. On the other hand, Boon et al. (1999) did not consider certain aspects, such as galactose mutarotation (Bakken et al., 1992), allolactose production (Huber et al., 1976), and the separate production of GOS-3 and GOS-4 (Iwasaki et al., 1996), in their proposed model, unlike some models in the literature. They obtained the rate parameters using the King-Altman method in their simplified reaction model. Kim et al. (2004) achieved good agreement with experimental data not only in lactose hydrolysis but also at various substrate concentrations using their proposed GOS synthesis reaction model. Their model includes the formation of allolactose, glucose's participation as a reactant, and enzyme concentration as parameters. In this model, lactose serves both as a substrate and a weaker glycosyl acceptor; however, at high concentrations, it has a higher chance of being an acceptor for GOS-3 synthesis. Galactose forms a complex with the free enzyme to create the galactosyl-enzyme complex, acting as an acceptor alongside glucose or lactose for subsequent transgalactosylation reactions. Notably, it does not bind to the galactosyl-enzyme complex. On the other hand, glucose, through interaction solely with the galactosyl-enzyme complex, functions as a more effective acceptor for transgalactosylation reactions, resulting in the formation of galactosyl-glucose disaccharides. The reaction mechanism assumes only one rate-limiting step and that all other steps are reversible. In their model, Neri et al. (2009) introduced competitive inhibition by glucose and galactose to trisaccharide synthesis and lactose hydrolysis reactions. The model comprises four dependent state variables (lactose, glucose, galactose, and trisaccharide concentration) and eight kinetic parameters. Additionally, this model assumes the reversibility of oligosaccharide synthesis, allowing water or lactose to interact with the galactosyl-enzyme complex. The model does not consider galactose mutarotation, tetrasaccharide formation, diffusion limitations, and time-dependent enzyme inactivation, focusing only on using lactose as a substrate. Moreover, Palai et al. (2012), Palai and Bhattacharya (2013), Palai et al. (2014), and Palai et al. (2016) used reaction models based on the Michaelis-Menten model to perform kinetic analysis for GOS synthesis. Palai et al. (2012) used a four-step model to simplify the reaction mechanism. In this model, synthesized GOS-3 and GOS-4 are expressed as a single product, GOS. No distinction is made between glucose and galactose; both being referred to as monosaccharides. Additionally, enzyme inhibition is neglected. Palai et al. (2014) and Palai et al. (2016) used a five-step reaction model in their studies. In this model, the formation of glucose and galactose is considered separately, and GOS hydrolysis and glucose's competitive inhibition are taken into account. 3, 4, and possible higher-chain GOS are expressed as GOS.

The complexity of the synthesis mechanism for GOS production, where transgalactosylation and hydrolysis reactions occur simultaneously, increases due to different reactions having different substrates and ratios (González-Delgado et al., 2016). Therefore, it is crucial to explore various methods for analysing and optimizing

the GOS synthesis process. The enzymatic synthesis of GOS is a reaction that is controlled kinetically and heavily relies on enzyme properties. Factors such as the enzyme source, lactose conversion, productivity, and product composition are affected by the choice of enzyme source (Özdiñç and Velioglu, 2022). *A. oryzae*-derived  $\beta$ -galactosidase stands out for its high specific activity, resistance to high temperatures, and cost-effectiveness. However, due to the low lactose conversion of this enzyme in GOS synthesis, it is vital to enhance the GOS yield by optimizing reaction conditions through optimization methods. For this reason, a specific focus on comprehending the kinetic mechanism of this enzyme is essential.

In light of this information, the aim of this study is to adapt experimental data to a mathematical model using the transgalactosylation mechanisms identified in the literature for GOS synthesis and lactose hydrolysis. Predicting the reaction rate constants will enable the estimation of the GOS amount at any given point in the reaction process, allowing for a more reliable assessment of GOS synthesis efficiency under different reaction conditions catalysed by *A. oryzae*-derived  $\beta$ -galactosidase.

## 2. Materials and Methods

### 2.1. Materials

$\beta$ -galactosidase sourced from *A. oryzae*, with fungal lactase activity at 100000 U g<sup>-1</sup>, was acquired from ENZECO® (Enzyme Development Corporation, New York, USA). Lactose (99.9%) and all other reagents with the highest purity were obtained from Sigma-Aldrich Chemie GmbH (Taufkirchen, Germany). For the purpose of determining retention times in HPLC, glucose (Merck, Darmstadt, Germany) and galactose (Merck, Darmstadt, Germany) were utilized.

### 2.2. Methods

#### 2.2.1. GOS Synthesis in the Continuous Stirred Tank Reactor

The synthesis of GOS was conducted using a temperature-controlled magnetic stirrer (MTops MS300HS, South Korea). Lactose solution (LS) by weighing 50 g was placed on the magnetic stirrer (Cinar et al., 2020). The lactose solution was formulated at the optimal operational pH for lactase enzyme (pH:4.5). Adjustments to the pH of reaction medium were made using 0.1 N HCl and 0.1 N NaOH solutions as required. To pinpoint the moment of peak GOS production during synthesis, 100  $\mu$ l samples were extracted from the reaction medium at specific time intervals (5-30 minutes). Enzyme inactivation was accomplished by combining the samples with 900  $\mu$ l of distilled water at 95°C. Subsequently, the samples were preserved at -18°C until further analysis, which included HPLC examination of sugar profiles when necessary. The outcomes derived from the HPLC sugar peaks were expressed as the percentage proportion relative to the total sugars.

#### 2.2.2. HPLC Analysis

The Agilent 1260 Infinity HPLC system (Agilent Technologies, Santa Clara, CA, USA) was used for analysing the product profile obtained after enzymatic reaction. The system comprised a column oven (Agilent, G1316A), autosampler (Agilent G1329B), pump (Agilent, G1311C), a refractive index detector (SpectraSystem RI-150), and a software package (Agilent Chem-Station) for system control and data evaluation. For determining the sugar content of the products obtained after GOS synthesis, samples were diluted in a 1:9 ratios (100  $\mu$ l sample: 900  $\mu$ l 95°C distilled water) and injected into the system. Separation conditions are summarized in Table 1 (Cinar et al., 2020).

**Table 1 : Characteristics of the stationary and mobile phases for sugar analysis by HPLC.**

|                           |                                |
|---------------------------|--------------------------------|
| <b>Column</b>             | MetaCarb Ca Plus, 7.8 x 300 mm |
| <b>Column temperature</b> | 80°C                           |
| <b>Mobile phase</b>       | Deionized water (100%)         |
| <b>Injection volume</b>   | 20 $\mu$ l                     |
| <b>Flow rate</b>          | 0.5 mL min <sup>-1</sup>       |
| <b>Detector</b>           | Refractive index (RI), 16X     |

In the HPLC analyses, no standard was employed. The concentrations of sugars (lactose, glucose, galactose, and total GOS) were calculated in terms of weight percentages (w/w) based on the peak areas corresponding to

these sugars (Boon et al., 2000).

### 2.2.3. Kinetic Modelling of Enzymatic Galactooligosaccharide Synthesis

The activity ratio between transgalactosylation and hydrolysis reactions varies based on the enzyme source and production method in studies related to GOS synthesis. In this study, experimental data were adapted to kinetic models using transgalactosylation mechanisms identified in the literature for lactose hydrolysis and GOS synthesis. In this context, reaction mechanism models for GOS synthesis, Model A (Manucci, 2009) and Model B (Kim et al., 2004) were employed. Also, these models were modified by adding glucose and galactose inhibitions. For the adaptation of experimental data to a kinetic model and the estimation of reaction rate constants, the COPASI 4.22 software package, enabling the modelling of biochemical systems, was utilized. The analysis was conducted using the "random research" and "particle swarm" algorithms. COPASI is extensively utilized for the kinetic modelling of biochemical reactions, offering essential features like various parameter estimation algorithms, support for metabolic control analysis, and the ability for users to export data in the SBML format (Costa and Vinga, 2016). The kinetic parameters of the proposed models were determined using nonlinear regression techniques with experimental data sets. For calculating molar concentrations, the molecular weights of lactose, galactose, and glucose were assumed to be 342.3 g moles<sup>-1</sup>, 180.16 g moles<sup>-1</sup>, and 180.16 g moles<sup>-1</sup>, respectively. The molecular weight of synthesized GOS was assumed to be GOS-3, with a molecular weight of 504.32 g moles<sup>-1</sup> (Warmerdam et al., 2013). The molecular weight of *A. oryzae*-derived  $\beta$ -galactosidase enzyme was considered as 105000 Da (Tanaka et al., 1975).

In this study, models identified in the literature for modelling GOS synthesis were applied to the obtained data. Subsequently, these models, along with modifications, were tested against experimental datasets to adapt them to GOS synthesis. A total of eight models were assessed for their appropriateness using six replicated experimental datasets at the specified reaction conditions: temperature (45°C), lactose concentration (18.25°Brix), and enzyme concentration (10 U g lactose solution<sup>-1</sup>). The analyses and time-course simulations were conducted using COPASI 4.22 software, employing a deterministic LSODA solver (Hoops et al., 2006). The reaction mechanisms of the eight models used in the study are illustrated in Figure 3, i-viii. In these model equations, 'E' represents enzyme, 'Glu' stands for glucose, 'Gal' for galactose, 'Lac' for lactose, 'GOS' for total galactooligosaccharides, 'E:Lac' for enzyme-lactose complex, 'E:Gal' for enzyme-galactose complex, 'Allo' for allolactose, 'E:IGlu' signifies the glucose inhibited enzyme complex, 'E:IGal' signifies the galactose inhibited enzyme complex.

## 3. Results and Discussion

### 3.1. Evaluation of enzymatic synthesis

At the initial moment of the reaction ( $t=0$ ), only lactose was present in the reaction medium. Therefore, at  $t=0$ , the entire component present in the medium constitutes lactose at 100% (Figure 1-2). The amount of lactose decreased throughout the reaction due to transgalactosylation and hydrolysis reactions. It was found that approximately 60% of initial lactose was converted into other reaction components in the 300-minute reaction time (Figure 1). The mean scores of six enzymatic synthesis experiments revealed that maximum GOS yield was achieved at the reaction time of  $78.75 \pm 3.75$  min. At this time obtained weight percentages of GOS-4, GOS-3 and GOS yield was  $4.76 \pm 0.19$ ,  $16.75 \pm 0.28$  and  $21.51 \pm 0.12$ , respectively. As can be seen from Figure 1, after reaching peak values of GOS-3 and GOS-4, they began to degrade. At low lactose conversions, transgalactosylation is predominant in the early stages of the reaction, and when GOS yield reaches its maximum level, hydrolysis becomes dominant (Cinar et al., 2020). Moreover, Osman et al. (2016) explained that the rates of transgalactosylation and hydrolysis reactions reached equilibrium, and GOS Yield (GY) continued to increase up to a certain level. And after this point, GOS hydrolysis became dominant over transgalactosylation, and glucose and galactose became thermodynamically preferred products.

During GOS synthesis, the sequential enzymatic transfer of galactose to glucose and galactose, resulting in the formation of certain double-chain saccharides like allolactose and galactobiose, is possible (Neri et al., 2009). These reactions are considered intermediate steps in GOS synthesis and are transient. Throughout the reaction, they either act as galactosyl acceptors or are hydrolyzed by the enzyme into galactose and glucose (Huber et al., 1976). As observed from the obtained HPLC chromatograms (Figure 2), it is not possible to determine whether

these side reactions occur during the reaction. Additionally, it has been determined that *A. oryzae*-derived  $\beta$ -galactosidase produces negligible amounts of transgalactosyl disaccharides (Cheng et al., 2006; Huerta et al., 2011; Sanz-Valero, 2009; Vera et al., 2011). It has been reported that it predominantly produces GOS-3, a small amount of GOS-4, and negligible levels of GOS-2 and GOS-5 (Osman, 2016).

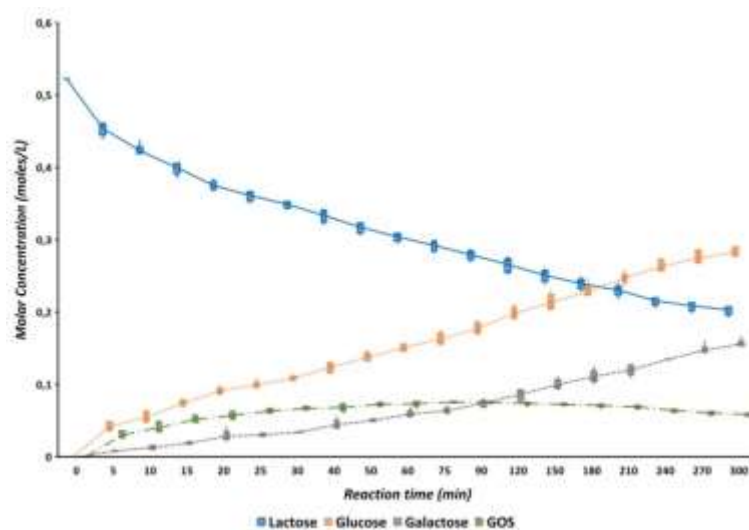


**Figure 1.** Time dependent change of molar concentrations of reaction components (Reaction conditions: temperature (45°C), lactose concentration (18.25°Brix), and enzyme concentration (10 U g lactose solution<sup>-1</sup>).

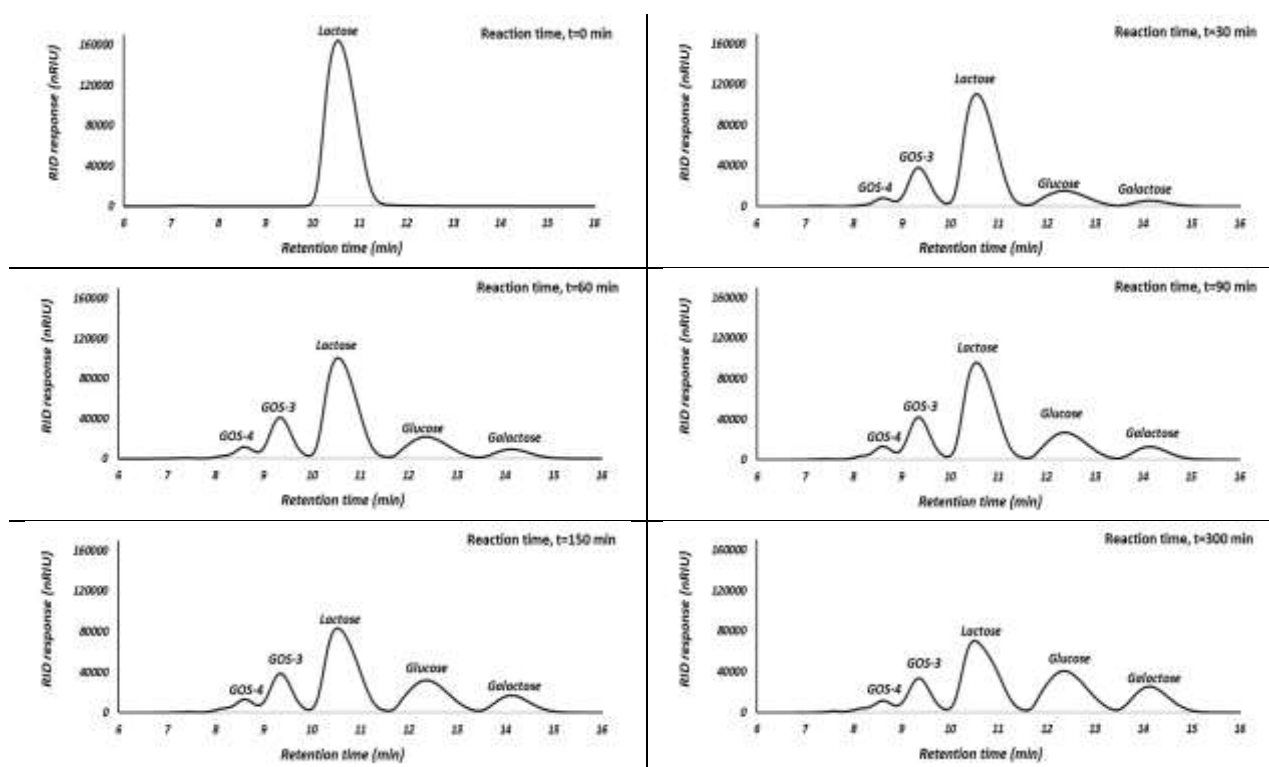


**Figure 2.** HPLC chromatograms showing the change of reaction components with time (Reaction conditions: temperature (45°C), lactose concentration (18.25°Brix), and enzyme concentration (10 U g lactose solution<sup>-1</sup>).

The possibility of the formation of high-chain GOS with different structures during the reaction exists, and their absence in HPLC detection is also possible. In literature studies, double-chain GOS such as allolactose and galactobiose were assumed to be included in the lactose peak (Jenab et al., 2018; Manucci, 2009). In this study, it was also thought that the amount of allolactose is included in the lactose peak. Since allolactose, like lactose, acts as a galactosyl acceptor, this does not pose a problem in terms of the synthesis mechanism. Urrutia et al.

(2013) highlighted the significant contribution of disaccharides to the overall GOS content, an aspect often overlooked in the case of *A. oryzae*  $\beta$ -galactosidase. This oversight occurs because disaccharides are typically concealed by lactose when employing conventional analytical methods. They also added that the mechanism of allolactose formation is essentially an intermolecular reaction for this  $\beta$ -galactosidase. Furthermore, the molar balances of galactose and glucose throughout the reaction were monitored using the following equation, as done by Boon et al. (1999).

$$\frac{[glucose]}{[galactose]} = \frac{[lactose] + [glucose] + [GOS]}{[lactose] + [galactose] + 2[GOS]} \quad (\text{Eq. 1})$$

Since no standards were used in HPLC, and the quantities of reaction products were calculated as percentages, the molar ratio of glucose to galactose changes slightly during the reaction. The theoretical ratio, which should be "1," is considered to have an acceptable error margin of 10%, as evaluated by Boon et al. (1999)

### 3.2. Kinetic modelling

In an attempt to balance between an overly simplified model and inappropriately predicted rate constants, existing GOS synthesis models aim to match experimental data. The procedure commonly applied in studies to report kinetic parameters involves providing parameter, standard error, or standard deviation for each fit in each experimental set (Manucci, 2009). Statistical errors can be reported for each experimental set using multiple nonlinear regression techniques (Bates and Watts, 1988). Also, in this study the kinetic parameters of the proposed models were determined using the nonlinear regression technique with experimental datasets. The equation for the objective function used to predict kinetic rate constants is given below.

$$f(k) = \sum_{i,j} \frac{[\tilde{y}_{i,j} - y_{i,j}(k)]^2}{\langle \tilde{y}_i^2 \rangle} \quad (\text{Eq. 2})$$

In this equation, " $f(k)$ " represents the objective function of the rate constants, " $\tilde{y}$ " denotes the experimental data, and " $y$ " represents the simulated data. The subscripts " $i$ " and " $j$ " represent reaction elements and experimental data, respectively. The initial concentrations of reaction elements (glucose, galactose, GOS) and intermediate elements (E:Lac, E:Gal, Allo, E:IGlu, E:IGal) were taken as zero. Graphs depicting the time-dependent changes in reaction elements obtained from testing the appropriateness of eight models against six replicated experimental datasets are shown below (Figure 3). The graphs were directly obtained from the software; the x-axis represents time in minutes, and the y-axis represents molar concentration.

There is no good fit between experimental and simulated data in Model A (Figure 3i). It can be stated that up to 100 minutes of reaction time, there is conformity between the GOS and galactose values, but after this time, this trend collapses. However, the predicted individual fittings of lactose and glucose show poor matching with the experimental measurements throughout the reaction. Additionally, the weighted errors grow larger as the reaction continues. When galactose (Figure 3ii) and glucose (Figure 3iii) inhibitions are added to Model A, except for GOS, the fitness of lactose, glucose, and galactose almost shows a similar pattern with the simulated data of Model A (Figure 3i). It was observed that especially glucose exhibits extremely poor fitness between experimental and simulated data. Also, the fitness of simulated data of lactose was still better than the data of "Model A" and "Model A + glucose inhibition." Therefore, we can say that these models are not appropriate for making proper estimations of the experimental data. However, with the addition of glucose and galactose inhibitions to Model A (Figure 3iv), we can obtain better estimates than Figures 3i-iii. Especially, there was a good correlation between the time-dependent data of galactose and GOS and the simulated ones. The simulated data of lactose and glucose were well-fitted between the reaction times of 120 and 220; however, before and after these time ranges, the difference between the observations and the corresponding fitted values increased, so the appropriateness of the model to estimate reaction constants worsened. Hence, the ability of these models (Figure 3i-iv) to represent the time-dependent change in concentrations of reaction components during the GOS synthesis process was found to be incompatible.

When examining Model B (Figure 3v), it can be noted that there was an overlap for lactose, galactose, and GOS only until 100 minutes between the experimental and corresponding fitted data. However, this trend collapsed after this time. On the other hand, there was a marked difference between experimental and simulated data of glucose, as indicated by the increase in weighted errors over the reaction time (Figure 3v). The graph of



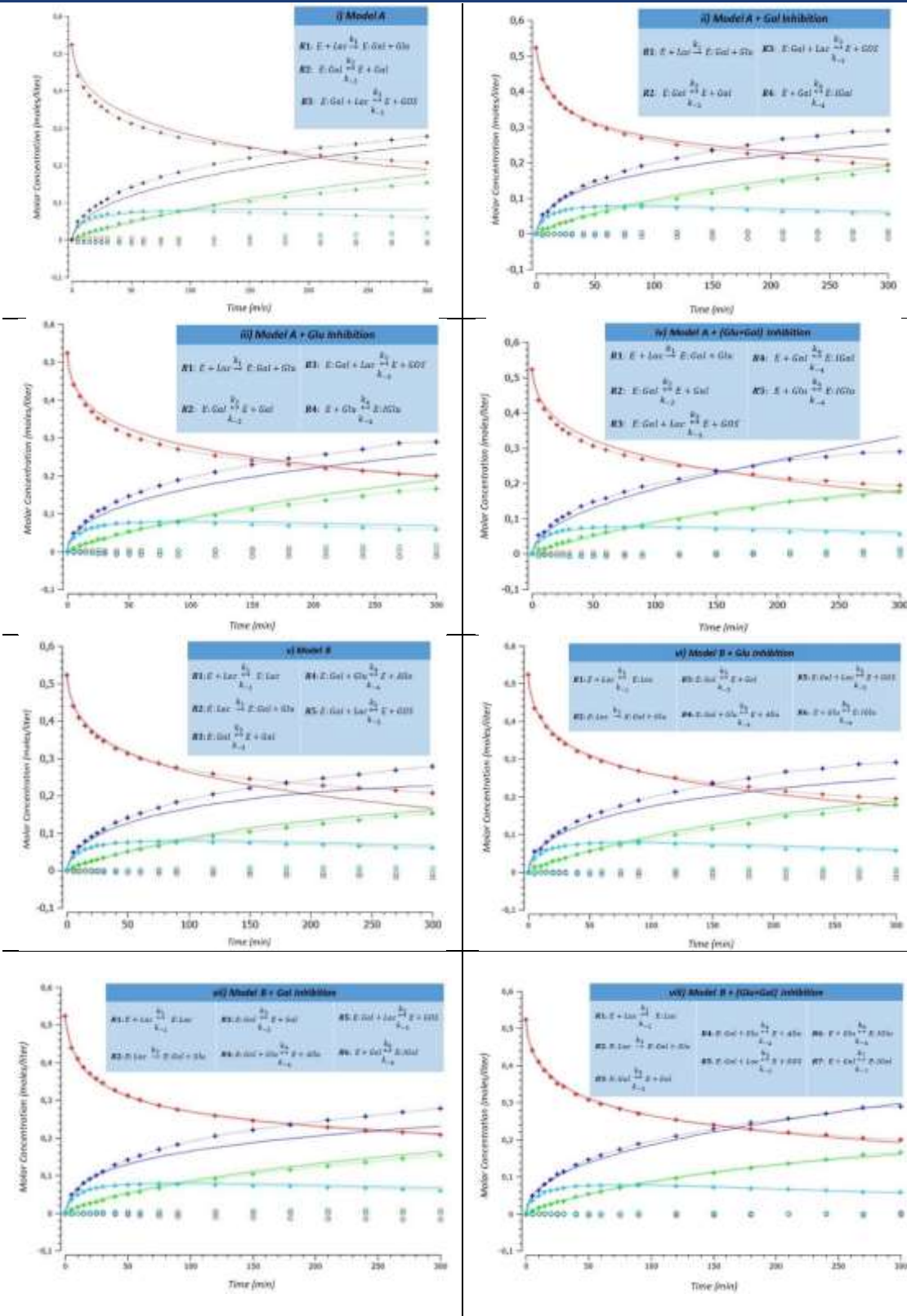


**Figure 3.** Schematic representations of experimental values and simulated values of eight models (- [GOS] Fitted Value, + [GOS] Measured Value, O [GOS] Weighted Value, - [Gal] Fitted Value, + [Gal] Measured Value, O [Gal] Weighted Value, - [Glu] Fitted Value, + [Glu] Measured Value, O [Glu] Weighted Value, - [Lac] Fitted Value, + [Lac] Measured Value, O [Lac] Weighted Value) (Reaction conditions: temperature (45°C), lactose concentration (18.25°Brix), and enzyme concentration (10 U g lactose solution<sup>-1</sup>).



Model B, including glucose inhibition (*Figure 3vi*), indicated that although the fitness of lactose extended over 130 minutes, the same arguments for that of Model B (*Figure 3v*) were also valid. However, the addition of only galactose inhibition to Model B demonstrated a perfect fitness for lactose between the experimental and corresponding fitted data (*Figure 3vii*). Also, the fitness of galactose and GOS could be accepted as tolerable for a 300-minute reaction time, since the weighted errors of them were close to zero. However, the fitness of glucose broke the compatibility of the model, resulting in large residuals during the process (*Figure 3vii*). When the inhibition reactions of glucose and galactose were added to Model B (*Figure 3viii*), this new model provided optimal estimations for all of the reaction components. The fitness of lactose, glucose, galactose, and GOS was acceptable. The predicted individual fittings of galactose, GOS, and especially glucose showed the best matching with the experimental measurements throughout the reaction. This can be inferred from the data of weighted errors of reaction components, each of which was almost zero. Therefore, it becomes evident that the graph identified as "viii) Model B + glucose and galactose inhibition" in Figure 3 exhibits the closest alignment between experimental and simulated data.

The differential equations (Eq. 3-12) presented below illustrate the time-dependent alterations in each element within this seven-step model, where terms in square brackets denote the molar concentration of each element. The kinetic parameters in the reaction model describing GOS synthesis and lactose hydrolysis are expressed in the following units:  $k_1$ ,  $k_{-3}$ ,  $k_4$ ,  $k_{-4}$ ,  $k_5$ ,  $k_{-5}$ ,  $k_6$ , and  $k_7$  have units of  $L \text{ moles}^{-1} \text{ s}^{-1}$ , while  $k_{-1}$ ,  $k_2$ ,  $k_3$ ,  $k_{-6}$ , and  $k_{-7}$  have units of  $\text{s}^{-1}$ .

$$\frac{d[Lac]}{dt} = -k_1[E][Lac] + k_{-1}[E:Lac] - k_5[E:Gal][Lac] + k_{-5}[E][GOS] \quad (\text{Eq. 3})$$

$$\frac{d[E]}{dt} = -k_1[E][Lac] + k_{-1}[E:Lac] + k_3[E:Gal] - k_{-3}[E][Gal] + k_4[E:Gal][Glu] - k_{-4}[E][Allo] + k_5[E:Gal][Lac] - k_{-5}[E][GOS] - k_6[E][Glu] + k_{-6}[E:IGlu] - k_7[E][Gal] + k_{-7}[E:IGal] \quad (\text{Eq. 4})$$

$$\frac{d[E:Gal]}{dt} = k_2[E:Lac] - k_3[E:Gal] + k_{-3}[E][Gal] - k_4[E:Gal][Glu] + k_{-4}[E][Allo] - k_5[E:Gal][Lac] + k_{-5}[E][GOS] \quad (\text{Eq. 5})$$

$$\frac{d[Glu]}{dt} = k_2[E:Lac] - k_4[E:Gal][Glu] + k_{-4}[E][Allo] - k_6[E][Glu] + k_{-6}[E:IGlu] \quad (\text{Eq. 6})$$

$$\frac{d[Gal]}{dt} = k_3[E:Gal] - k_{-3}[E][Gal] - k_7[E][Gal] + k_{-7}[E:IGal] \quad (\text{Eq. 7})$$

$$\frac{d[GOS]}{dt} = k_5[E:Gal][Lac] - k_{-5}[E][GOS] \quad (\text{Eq. 8})$$

$$\frac{d[Allo]}{dt} = k_4[E:Gal][Glu] - k_{-4}[E][Allo] \quad (\text{Eq. 9})$$

$$\frac{d[E:Lac]}{dt} = k_1[E][Lac] - k_{-1}[E:Lac] - k_2[E:Lac] \quad (\text{Eq. 10})$$

$$\frac{d[E:IGlu]}{dt} = k_6[E][Glu] - k_{-6}[E:IGlu] \quad (\text{Eq. 11})$$

$$\frac{d[E:IGal]}{dt} = k_7[E][Gal] - k_{-7}[E:IGal] \quad (\text{Eq. 12})$$

This particular model that provide optimal fittings; accounts for the competitive inhibition of galactose and glucose, addresses the hydrolysis of GOS, treats the formation of glucose and galactose separately, represents all oligosaccharides with four chains, five chains, or more as GOS, assumes the irreversibility of the breakdown of the enzyme-lactose complex into the enzyme-galactose complex, disregards diffusional constraints, functions as either a substrate or glycosyl acceptor depending on lactose concentration, involves glucose reacting with the E:Gal complex to produce glucose-galactose disaccharides (allolactose), disregards the thermal deactivation of the enzyme. This study demonstrated that glucose and galactose inhibitions are important step for GOS synthesis mechanism. The primary reason for this phenomenon is believed to be the increased concentration of monosaccharides, especially galactose, exerting an inhibitory effect on the enzyme as the reaction progress. Indeed, galactose has been indicated as a competitive inhibitor in the literature in many studies on lactose hydrolysis reactions (Freitas et al., 2011; Rodriguez-Fernandez et al., 2011; Yin et al., 2017). Vera et al. (2011) have reported that the inhibitory effect of galactose is significantly stronger in transgalactosylation reactions

compared to lactose hydrolysis. Galactose is recognized as a competitive inhibitor for the enzyme's active site, competing with lactose (Hsu et al., 2007). This competitive inhibition is known to greatly slow down the enzyme's actions, leading to a decrease in reaction rate, particularly in reactions involving high lactose conversions (Iqbal et al., 2023; Sanz-Valero, 2009).

While some researchers have reported that glucose does not function as an inhibitor in the reaction kinetics of *A. oryzae*-derived  $\beta$ -galactosidases (Mueller et al., 2018; Shin and Ji-Won, 1998), others have explained the inhibitory effects of glucose (Palai et al., 2012; Vera et al., 2011). Neri et al. (2009) have expressed that the presence of free galactose in the reaction medium reduces the lactose consumption rate of  $\beta$ -galactosidase obtained from *A. oryzae* more than the presence of glucose and lowers the maximum GOS yield both individually and in combination with both glucose and galactose. The release of glucose in the reaction medium is inevitable during transgalactosylation. Therefore, it is imperative to remove the free galactose and glucose in the reaction medium to achieve a higher yield of GOS. The development of new strategies and approaches to alleviate the inhibitory effect of monosaccharides will further enhance the synthesis performance of GOS. Also, this study revealed that inhibitions of monosaccharides are important reaction steps for determination of appropriate kinetic reaction model for the synthesis of galactooligosaccharides catalysed by  $\beta$ -galactosidase from *A. oryzae*.

#### 4. Conclusions

After rigorous analysis and comparison, it was found that Model B, enhanced with glucose and galactose inhibitions, demonstrated the closest agreement between experimental and simulated data. The proposed model effectively accounted for both lactose hydrolysis and GOS synthesis, providing a comprehensive understanding of the reaction pathway. The study highlighted the complexity of the GOS synthesis mechanism, where transgalactosylation and hydrolysis reactions occur simultaneously, necessitating a balance between model accuracy and feasibility. The incorporation of glucose and galactose inhibitions in Model B proved crucial in improving the model's ability to predict GOS synthesis efficiency under specified reaction conditions. Furthermore, the research emphasized the importance of understanding the kinetic mechanism of *A. oryzae*-derived  $\beta$ -galactosidase, considering its significant influence on factors such as conversion of lactose, productivity, and composition of product. The inhibitory effects of monosaccharides were identified as key factors influencing the enzyme's performance, leading to the development of a more accurate and reliable kinetic model. The adapted Model B with glucose and galactose inhibitions emerges as a valuable tool for predicting GOS yield at different time points during the reaction process. The findings contribute to the advancement of knowledge in enzymatic GOS synthesis and provide insights that can guide further optimization strategies for enhancing GOS production efficiency.

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#### Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

#### Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

#### Authorship Contribution Statement

Concept: Cinar, K., Gulec, H.A., Gunes, G.; Design: Cinar, K., Gulec, H.A.; Data Collection or Processing: Cinar, K.; Statistical Analyses: Cinar, K.; Literature Search: Cinar, K., Gulec, H.A.; Writing, Review and Editing: Cinar, K., Gulec, H.A., Gunes, G.

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**Determination of Plant Parasitic Nematodes by Using Morphological-Morphometric Methods in Some Golf Courses of Antalya Province (Türkiye)**

Antalya İli (Türkiye) Golf Alanlarındaki Bitki Paraziti Nematodların Morfolojik-Morfometrik Yöntemlerle Belirlenmesi

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**Abstract**

The importance of green areas in today's modern city concept is increasing day by day. In this understanding, the use of turfgrass [ e.g. Bentgrass (*Agrostis* spp. L.); Kentucky Bluegrass (*Poa pratensis* L.); Common Bermudagrass *Cynodon dactylon* (L.) Pers. (Poales: Poaceae)] in sports fields is getting important. Golf courses mainly occurs turfgrass and not much nematological studies has been done in courses of Türkiye. In this study, total of 51 soil and 3 water samples were taken from golf courses in Antalya, Türkiye's largest golf tourism destination, in 2021. Within the scope of this study, plant parasitic nematode (PPN) species belonging to the genera *Aphelenchoides* Fischer, 1894 (Tylenchida: Aphelenchoididae), *Aphelenchus* Bastian, 1865 (Tylenchida: Aphelenchoididae), *Criconebella* (De Grisse & Loof, 1965) (Tylenchida: Criconematidae), *Ditylenchus* Filipjev, 1936 (Tylenchida: Anguinidae), *Helicotylenchus* Steiner, 1945 (Tylenchida: Hoplolaimidae), *Hemicriconebellus* Chitwood & Birchfield, 1957 (Tylenchida: Criconematidae), *Hemicycliophora* de Man, 1921 (Tylenchida: Hemicycliophoridae), *Hoplolaimus* von Daday, 1905 (Tylenchida: Hoplolaimidae), *Longidorus* Micoletzky, 1922 (Dorylaimida: Longidoridae), *Paratrichodorus* Siddiqi, 1974 (Triplonchida: Trichodoridae) and *Tylenchus* Bastian, 1865 (Tylenchida: Tylenchidae) were identified using morphological and morphometric methods. The most detected species in the samples was *Hemicycliophora punensis* Darekar & Khan, 1980 (Rhabditida: Hemicycliophoridae) (22.22%), while the least detected PPN species was *Helicotylenchus dihystra* (Cobb, 1893) Sher, 1961 (Tylenchida: Hoplolaimidae) (3.70%). In this study, it is important there are virus vector species among the identified plant parasitic nematode genera. These nematode species can play an active role in the spread of various viral diseases in turfgrass areas. In turfgrass areas where very sensitive cultivation is carried out, such as golf courses, PPN's cause direct damages by feeding, which serve as the source of entry of pathogens into the plants. This situation increases the prevalence and severity of the disease in infected fields. Therefore, early detection of the presence of PPN's in cultivation areas is important to determine effective control strategies.

**Keywords:** Golf, Morphological identification, Plant parasitic nematodes, Turfgrass

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## Öz

Günümüz modern şehir anlayışında yeşil alanların önemi her geçen gün artmaktadır. Bu anlayış içerisinde çimin [örneğin Bentgrass (*Agrostis* spp. L.); Kentucky Bluegrass (*Poa pratensis* L.); Common Bermudagrass *Cynodon dactylon* (L.) Pers. (Poales: Poaceae)] spor alanlarında kullanımı ise giderek önem arz etmektedir. Golf alanları çimin kullanıldığı ve ülkemizde nematolojik açıdan üzerinde çok fazla çalışmanın yapılmadığı bir alandır. Bu çalışmada, 2021 yılında Türkiye'nin en büyük golf turizmi merkezi olan Antalya'daki golf sahalarından toplam 51 toprak ve 3 su örneği alınmıştır. Yapılan çalışma kapsamında *Aphelenchoides* Fischer, 1894 (Tylenchida: Aphelenchoididae), *Aphelenchus* Bastian, 1865 (Tylenchida: Aphelenchoididae), *Criconebella* (De Grisse & Loof, 1965) (Tylenchida: Criconebellidae), *Ditylenchus* Filipjev, 1936 (Tylenchida: Anguinidae), *Helicotylenchus* Steiner, 1945 (Tylenchida: Hoplolaimidae), *Hemicriconebellus* Chitwood & Birchfield, 1957 (Tylenchida: Criconebellidae), *Hemicycliophora* de Man, 1921 (Tylenchida: Hemicycliophoridae), *Hoplolaimus* von Daday, 1905 (Tylenchida: Hoplolaimidae), *Longidorus* Micoletzky, 1922 (Dorylaimida: Longidoridae), *Paratrichodorus* Siddiqi, 1974 (Triplonchida: Trichodoridae) ve *Tylenchus* Bastian, 1865 (Tylenchida: Tylenchidae) cinslerine ait bitki paraziti nematod (BPN) türleri morfolojik morfometrik metodlar kullanılarak tanımlanmıştır. Alınan örneklerde en çok tespit edilen tür *Hemicycliophora punensis* Darekar & Khan, 1980 (Rhabditida: Hemicycliophoridae) (%22.22) olurken, en az tespit edilen tür ise *Helicotylenchus dihystra* (Cobb, 1893) Sher, 1961 (Tylenchida: Hoplolaimidae) (%3.70) olmuştur. Bu çalışmada tanımlanan bitki paraziti nematod türleri içerisinde virüs vektörü türlerin olması önemlidir. Bu türler çim alanlarında çeşitli viral hastalıkların yayılmalarında etkin rol oynayabilecektir. Golf alanları gibi çok hassas bir yetiştiriciliğin yapıldığı çim alanlarında BPN'lar, beslenerek doğrudan yapmış oldukları zararların yanında toprak kökenli çeşitli hastalık etmenlerinin bitkilere girişlerine de neden olmaktadır. Bu da hastalığın yaygınlığını ve şiddetini arttırmaktadır. Dolayısıyla üretim alanlarındaki BPN varlığının erken dönemlerde belirlenmesi etkili mücadele stratejilerinin belirlenmesi için önemlidir.

**Anahtar Kelimeler:** Golf, Morfolojik tanımlama, Bitki paraziti nematodlar, Çim



## 1. Introduction

Grasses (Poaceae or Gramineae) is the second most diverse family among monocotyledons (Finot et al., 2011). Turfgrasses are used as sports fields, lawns of homes, other recreational facilities, railways and roadsides (Ye et al., 2015). The most important sport facilities where grass areas are used extensively are golf courses. Additionally, golf is the primary producer and consumer of turf (McClure et al., 2012). While there are approximately 36.000 golf courses worldwide, this number is approximately 16.000 in the United States and 35 in Türkiye (Lyman et al., 2007; Doytchev, 2019; TGF, 2023). Antalya province has the largest share in Türkiye in this field with 20 (57.14%) golf areas (TGF, 2023).

Many abiotic and biotic factors can cause damage to grass. Floods, nutrient deficiencies, fertilization and pesticide damage are among the abiotic factors that cause damage to turfgrass. Biotic factors such as bacteria, fungi, viruses, mycoplasma and nematodes can drastically decrease the quality of turfgrass. Plant parasitic nematodes (PPNs) are one of the most important biotic factors responsible of damage to turfgrass areas (Vargas, 2018). It can cause regional turfgrass deaths, especially in some PPN-grass combinations and high inoculation densities (McClure et al., 2012; Mwamula and Lee, 2021). However, above-ground symptoms caused by PPNs can be confused with those of the symptoms that are caused by different abiotic and biotic factors (Coyne, 2007; Vandenbossche et al., 2011). Thus, of all turfgrass pests, PPNs are generally the least understood group and their symptoms often go unrecognized. Additionally, due to a lack of understanding of the effects of these pests on turfgrass health, it is difficult to accurately diagnose PPN-based problems (Zeng et al., 2012). Many studies have been carried out in different countries such as the USA (McClure et al., 2012; Zeng et al., 2012; Nischwitz et al., 2013; Ye et al., 2015; Crow et al., 2020), Canada (Yu et al., 1998; Wallace, 2016), China (Dong et al., 2022; Zeng et al., 2022), Belgium (Vandenbossche et al., 2011), Korea (Mwamula and Lee, 2021) and Türkiye (Akgül and Ökten, 1997; Uysal et al., 2023) to detect disease due to nematode species in turfgrass and golf areas. Many nematode species were identified in these studies. For instance, in a study conducted on 11 golf courses and 8 football fields in Belgium, 52 different species/taxons belonging to 23 genera and 9 families were identified morphologically (Vandenbossche et al., 2011). In another study conducted in 13 different golf areas in Korea, 28 species/taxa belonging to 16 genera and 12 families of PPNs were reported (Mwamula and Lee, 2021). In another study conducted in golf areas in Guangdong province, China, five plant-parasitic nematode species were detected (Zeng et al., 2022). Therefore, as determined in publications and contrary to general belief, more diverse and more nematode species can be found in turfgrass areas than thought (Vandenbossche et al., 2011). In this study aimed to identify plant parasitic nematode species in the golf areas of Antalya province, one of the most important golf destinations in Türkiye, using morphological and morphometric methods. To our knowledge, this research is the most detailed study conducted so far on the detection of PPNs in golf areas of Türkiye.

## 2. Material ve Methods

### 2.1. Sampling

Sampling in golf courses of Antalya, Türkiye, was conducted during May and June of 2021. In the sampling, areas consisting of stunted, wilted or yellowed plants and without clear boundaries were preferred. Soil and root samples were obtained from different parts of golf courses such as bunker, fairway, green, putting green, rough and tee. Samples were taken with a 2 cm diameter probe at a depth of 15-30 cm, including the upper grass layer. In total, 51 soil samples were taken from golf areas and football pitches (Table 1; Figure 1 and 2). Each sample consisted of 10-15 subsamples. All soil samples were placed in plastic bags with the sampling information and kept at 4-6°C in cold chain sample carrying boxes before being transferred to laboratory. In addition, 3 water samples were taken from the water sources used to irrigate the areas.

### 2.2. Nematode extraction

Modified Baermann Funnel and Cobb's techniques were used to extraction of PPNs in soil and plant roots in samples taken from golf courses (Cobb, 1918; Hooper, 1986).

### 2.3. Preparation of PPNs

Nematodes obtained from the samples were washed several times in water/Ringer solution to remove any residue. The PPNs obtained were fixed in TAF (triethanolamine formalin) according to Seinhorst (1959) for morphological and

morphometric identification. Prepared nematodes were permanently mounted on glass slides using the wax-ring method (Hooper, 1986).



**Figure 1. Satellite image of the golf areas where samples were taken in Belek district of Antalya province (Anonymous, 2023).**



**Figure 2. Photographs of sampled areas consisting of stunted, wilted or yellowed plants with unclear boundaries (a), sample collection with probe (b).**

#### **2.4. Morphological and morphometric identification**

Permanent preparations were used in morphological and morphometric measurements. All measurements were carried out using a Leica DM1000 stereomicroscope and drawn with Adobe Illustrator program. Among the PPNs obtained, taxonomic evaluations of those belonging to Tylenchida were done based on Siddiqi (2000), and those belonging to Dorylaimida were evaluated according to Hunt (1993). Morphometric measurements of the examined individuals were defined morphologically by comparing them with measurement values obtained from different studies (Darekar and Khan, 1981; Loof, 1984; Elekçioğlu, 1992; Gutiérrez-Gutiérrez et al., 2011; Van den Berg et al., 2014).

#### **3. Results**

The PPN species belonging to 11 genera in 3 orders were detected in the sampled sites. These genera are as follows in alphabetical order: *Aphelenchoides* Fischer, 1894 (Tylenchida: Aphelenchoididae), *Aphelenchus* Bastian, 1865 (Tylenchida: Aphelenchoididae), *Criconemella* (De Grisse & Loof, 1965) (Tylenchida: Criconematidae), *Ditylenchus* Filipjev, 1936 (Tylenchida: Anguinidae), *Helicotylenchus* Steiner, 1945 (Tylenchida: Hoplolaimidae), *Hemicriconemoides* Chitwood & Birchfield, 1957 (Tylenchida: Criconematidae), *Hemicycliophora* de Man, 1921

**Table 1. Morphologic-morphometric analysis results and location information of samples obtained from golf areas in Antalya, Türkiye**

| Sample Code | Coordinates          | Identified species                |                                          |                                 |                                | Identified genus            |                          |                             |                       |                       |                               |                             |                         |                         |                         | Golf course sections* |                           |
|-------------|----------------------|-----------------------------------|------------------------------------------|---------------------------------|--------------------------------|-----------------------------|--------------------------|-----------------------------|-----------------------|-----------------------|-------------------------------|-----------------------------|-------------------------|-------------------------|-------------------------|-----------------------|---------------------------|
|             |                      | <i>Helicotylenchus dilhystera</i> | <i>Hemicriconemoides strictathecatus</i> | <i>Hemicycliophora punensis</i> | <i>Hemicycliophora iranica</i> | <i>Hemicycliophora</i> spp. | <i>Criconemella</i> spp. | <i>Paratrichodorus</i> spp. | <i>Tylenchus</i> spp. | <i>Longidorus</i> sp. | <i>Hemicriconemoides</i> spp. | <i>Helicotylenchus</i> spp. | <i>Ditylenchus</i> spp. | <i>Haplolaimus</i> spp. | <i>Aphelenchus</i> spp. |                       | <i>Aphelenchoids</i> spp. |
| GL1         | 36.858415, 31.059288 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL2         | 36.858309, 31.059141 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL3         | 36.856664, 31.062650 |                                   |                                          | +                               |                                | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | N                         |
| GL4         | 36.856165, 31.057495 |                                   |                                          |                                 | +                              | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL5         | 36.851617, 31.070078 | +                                 |                                          | +                               |                                | +                           |                          |                             |                       |                       | +                             | +                           |                         |                         |                         |                       | R                         |
| GL6         | 36.851286, 31.069828 |                                   |                                          |                                 |                                |                             | +                        | +                           |                       |                       |                               |                             |                         |                         |                         |                       | F                         |
| GL7         | 36.852216, 31.067865 |                                   |                                          | +                               |                                | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | R                         |
| GL8         | 36.856556, 31.061509 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | W                         |
| GL9         | 36.875578, 30.988356 |                                   |                                          |                                 |                                | +                           | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL10        | 36.875580, 30.988269 |                                   |                                          |                                 |                                |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL11        | 36.873048, 30.992029 |                                   |                                          | +                               |                                | +                           | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL12        | 36.873053, 30.991922 |                                   |                                          | +                               |                                | +                           | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL13        | 36.875610, 30.988825 |                                   |                                          |                                 |                                |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL14        | 36.875609, 30.988762 |                                   |                                          |                                 |                                |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL15        | 36.871721, 30.989739 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | G                         |
| GL16        | 36.871968, 30.991790 |                                   |                                          |                                 |                                | +                           | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | F                         |
| GL17        | 36.864924, 30.994386 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | W                         |
| GL18        | 36.860366, 31.043089 |                                   |                                          |                                 |                                | +                           |                          | +                           |                       |                       |                               |                             |                         |                         |                         |                       | F                         |
| GL19        | 36.860765, 31.041072 |                                   |                                          |                                 |                                | +                           | +                        |                             |                       |                       |                               |                             | +                       |                         |                         |                       | G                         |
| GL20        | 36.860991, 31.039552 |                                   |                                          |                                 |                                |                             | +                        |                             |                       | +                     |                               |                             |                         |                         |                         |                       | T                         |
| GL21        | 36.859568, 31.038487 |                                   |                                          | +                               |                                | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | F                         |
| GL22        | 36.858516, 31.039668 |                                   |                                          | +                               |                                | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | T                         |
| GL23        | 36.859963, 31.037059 |                                   |                                          | +                               |                                | +                           |                          | +                           |                       |                       |                               |                             |                         |                         |                         |                       | R                         |
| GL24        | 36.860097, 31.037042 |                                   | +                                        |                                 |                                | +                           |                          |                             |                       |                       | +                             |                             |                         |                         |                         |                       | G                         |
| GL25        | 36.856672, 31.049159 |                                   |                                          |                                 |                                |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | F                         |
| GL26        | 36.857223, 31.049336 |                                   |                                          | +                               |                                | +                           | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | T                         |
| GL27        | 36.860321, 31.048363 |                                   |                                          |                                 |                                |                             |                          |                             |                       | +                     |                               |                             |                         |                         |                         |                       | G                         |
| GL28        | 36.859234, 31.050749 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         | +                       |                         |                       | T                         |
| GL29        | 36.861575, 31.051585 |                                   |                                          |                                 |                                | +                           |                          |                             |                       | +                     |                               |                             |                         |                         |                         |                       | G                         |
| GL30        | 36.861316, 31.046656 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         | +                     | B                         |
| GL31        | 36.856651, 31.054584 |                                   |                                          |                                 |                                |                             |                          | +                           |                       |                       |                               |                             |                         |                         | +                       |                       | FP                        |
| GL32        | 36.863443, 31.040207 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | R                         |
| GL33        | 36.859948, 31.051499 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | W                         |
| GL34        | 36.846825, 31.090389 |                                   |                                          | +                               |                                | +                           | +                        |                             | +                     |                       |                               |                             |                         |                         |                         |                       | F                         |
| GL35        | 36.846803, 31.090404 |                                   |                                          |                                 |                                | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | R                         |
| GL36        | 36.849817, 31.095070 |                                   |                                          |                                 |                                |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                       | PG                        |
| GL37        | 36.849821, 31.095056 |                                   |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | PG                        |
| GL38        | 36.845829, 31.091027 | +                                 |                                          |                                 |                                |                             |                          |                             |                       |                       | +                             |                             |                         |                         |                         |                       | R                         |
| GL39        | 36.846393, 31.090625 |                                   |                                          |                                 |                                | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | R                         |
| GL40        | 36.851128, 31.087204 |                                   |                                          |                                 | +                              | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | F                         |
| GL41        | 36.851073, 31.087206 |                                   |                                          |                                 | +                              | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                       | R                         |

Table 1. (Continued)

| Sample Code | Coordinates          | Identified species               |                                          |                                 |                                | Identified genus            |                          |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       |    |
|-------------|----------------------|----------------------------------|------------------------------------------|---------------------------------|--------------------------------|-----------------------------|--------------------------|-----------------------------|-----------------------|-----------------------|-------------------------------|-----------------------------|-------------------------|-------------------------|-------------------------|---------------------------|-----------------------|----|
|             |                      | <i>Helicotylenchus dihystera</i> | <i>Hemicriconemoides strictathecatus</i> | <i>Hemicycliophora punensis</i> | <i>Hemicycliophora iranica</i> | <i>Hemicycliophora</i> spp. | <i>Criconemella</i> spp. | <i>Paratrichodorus</i> spp. | <i>Tylenchus</i> spp. | <i>Longidorus</i> sp. | <i>Hemicriconemoides</i> spp. | <i>Helicotylenchus</i> spp. | <i>Ditylenchus</i> spp. | <i>Haplolaimus</i> spp. | <i>Aphelenchus</i> spp. | <i>Aphelenchoids</i> spp. | Golf course sections* |    |
| GL42        | 36.845495, 31.106488 |                                  |                                          |                                 |                                | +                           |                          |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | G  |
| GL43        | 36.845525, 31.106555 |                                  |                                          |                                 | +                              |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | R  |
| GL44        | 36.846899, 31.107443 |                                  |                                          | +                               |                                |                             | +                        | +                           |                       | +                     |                               |                             |                         |                         |                         |                           |                       | T  |
| GL45        | 36.846812, 31.107313 |                                  |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | R  |
| GL46        | 36.852847, 31.091031 |                                  |                                          | +                               |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | T  |
| GL47        | 36.852889, 31.091057 |                                  |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | R  |
| GL48        | 36.847427, 31.100137 |                                  | +                                        |                                 |                                |                             |                          |                             |                       |                       |                               |                             | +                       | +                       |                         |                           |                       | F  |
| GL49        | 36.847497, 31.100154 |                                  |                                          |                                 |                                |                             |                          |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | R  |
| GL50        | 36.852749, 31.095725 |                                  |                                          |                                 |                                |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | G  |
| GL51        | 36.853157, 31.095006 |                                  |                                          |                                 |                                |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | R  |
| GL52        | 36.847164, 31.090374 |                                  |                                          |                                 |                                |                             |                          | +                           |                       |                       |                               |                             |                         |                         |                         |                           |                       | T  |
| GL53        | 36.847099, 31.088839 |                                  |                                          |                                 |                                |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | R  |
| GL54        | 36.851800, 31.088764 |                                  |                                          |                                 |                                |                             | +                        |                             |                       |                       |                               |                             |                         |                         |                         |                           |                       | FP |

\* Golf course sections: G: Green; R: Rough; T: Tee; F: Fairway; B: Bunker; N: Nursery; W: Water source; FP: Football Pitches; PT: Putting Green

(Tylenchida: Hemicyclophoridae), *Hoplolaimus* von Daday, 1905 (Tylenchida: Hoplolaimidae), *Longidorus* Micoletzky, 1922 (Dorylaimida: Longidoridae), *Paratrichodorus* Siddiqi, 1974 (Triplonchida: Trichodoridae) and *Tylenchus* Bastian, 1865 (Tylenchida: Tylenchidae).

The identified species were *Helicotylenchus dihystra* (Cobb, 1893) Sher, 1961 (Tylenchida: Hoplolaimidae), *Hemicriconemoides strictathecatus* Esser, 1960 (Tylenchida: Criconematidae), *Hemicyclophora iranica* Loof, 1984 (Tylenchida: Hemicyclophoridae) and *Hemicyclophora punensis* Darekar & Khan, 1980 (Tylenchida: Hemicyclophoridae) (Table 1). Measurement values of these PPNs were given in Tables 2-5. Among the samples taken, the most common genus was *Hemicyclophora* spp. (51.85%), while the least encountered genus was *Aphelenchoides* spp. (1.85%). The most common species was *H. punensis* (22.22%), and the least detected species was *H. dihystra* (3.70%). Additionally, genera including virus vector species such as *Longidorus* sp. were detected in the sampling areas (Table 1).

Soil samples were obtained from different parts of golf courses such as bunkers, fairways, greens, putting green, rough and tees, grass growing areas and football pitches. These areas were listed as green (29.62%), rough (25.92%), fairway (14.81%), tee (12.96%), water source (5.55%), football pitches (3.70%), putting green (3.70%), bunker (1.87%) and grass growing areas (1.87%), respectively, according to the sample collection amount (Table 1). In the evaluations made on the soil samples taken, no PPNs were detected in eight samples. These samples were obtained from rough (50%), green (37.5%), and putting green (12.5%) areas. Additionally, no PPNs were detected in any samples taken from water sources.

### 3.1. *Helicotylenchus* Steiner, 1945

#### 3.1.1. *Helicotylenchus dihystra* (Cobb, 1893) Sher, 1961

Examination of golf course samples in this study revealed *Helicotylenchus* nematodes in two samples and the occurrence rate of this species in the sampled areas is 3.70%. (Table 1). After fixation, the body takes a specific spiral shape. Stylet knobs are large, prominent, and rounded. The ovary is double, and its front and hind arms extend straight.



The tail is slightly short, usually with a small projection ventrally. As a result of the morphological and morphometric analyses, it was determined that these individuals were *H. dihystra* species (Figure 3 and 4) (Adobe Illustrator program was used for drawings). Morphometric measurement values of individuals of this species are given in Table 2.

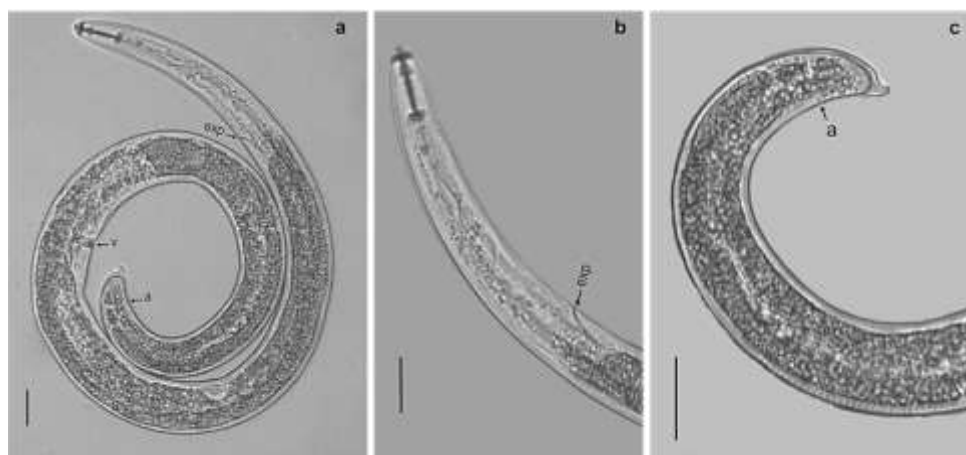


**Figure 3.** Female of *Helicotylenchus dihystra* (Cobb, 1893) Sher, 1961. (a): Entire body; (b): Anterior body; (c): Posterior body; a: Anus; v: Vulva; exp: Excretory pore (Scale bar: 20  $\mu$ m).

### 3.2. *Hemicriconemoides* Chitwood & Birchfield, 1957

#### 3.2.1. *Hemicriconemoides strictathecatus* Esser, 1960

Plant parasitic nematode individuals belonging to the *Hemicriconemoides* genus were detected in only two samples in this study. The prevalence of individuals of this species in the samples obtained from golf areas was 3.70%. (Table 1). The female body is slightly curved towards the ventral as a result of fixation. The body has a double cuticle and longitudinal grooves and indentations were observed on the body. Stylet knobs are anchor-shaped, featuring an indentation at the anterior end, a rounded posterior, large and inclined forward. The excretory pore is located 1-8 annuli

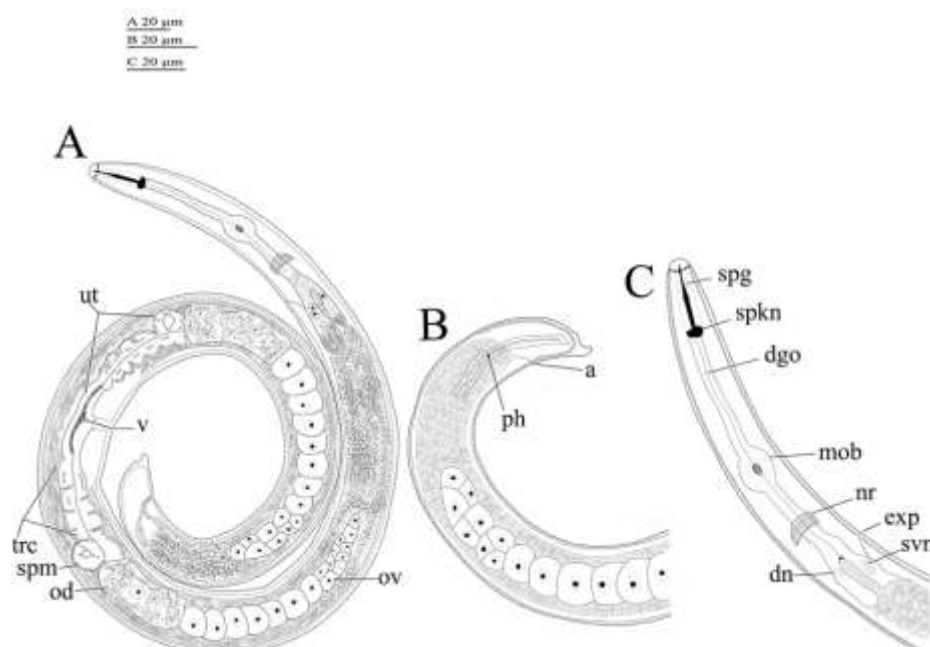


**Figure 4.** Female of *Helicotylenchus dihystra* (Cobb, 1893) Sher, 1961. (A): Entire body; (B): Posterior body; (C): Anterior body (dgo: dorsal gland opening, spg: stylet guide, mob: median bulb, spkn: stylet knobs, nr: nerve ring, svn- sub: ventral gland nuclei, dn: dorsal pharyngeal gland nucleus, ph: phasmid, a: anus, v: vulva, ov: ovary, od: oviduct, spm: spermatheca, trc: tricolomella, exp: excretory pore, ut: uterus).

posterior to the base of the pharynx (Van den Berg et al., 2014). Anus is situated 2-4 annuli posterior to the vulva (Van den Berg et al., 2014; 2015). The tail has a conical like structure that tapers towards the tip. The tail narrows to a bluntly pointed tip in some specimens, while in others, it narrows only slightly, ending in a broadly rounded terminus (Van den Berg et al., 2015). It was determined that the examined samples were of the *H. strictathecatus* (Figure 5). Morphometric measurements of individuals belonging to the *H. strictathecatus* species are given in Table 3.

**Table 2. Basic morphometric measurement values of *Helicotylenchus dihystra* nematodes obtained from golf areas in Antalya province**

| Diagnostic Characters        | This Study<br>(n: 2 ♀)   | Elekçioğlu (1992)<br>(n: 10 ♀) |
|------------------------------|--------------------------|--------------------------------|
| Body length                  | 620.0±75.6 (566.5-673.4) | 630.0±20.0 (580.0-710.0)       |
| Body width                   | 25.2±2.9 (23.1-27.3)     | -                              |
| Body width at stylet base    | 14.5±0.4 (14.2-14.8)     |                                |
| Body width at anus           | 15.3±1.5 (14.3-16.4)     |                                |
| Stylet length                | 27.2±0.8 (26.6-27.7)     | 26.0 ± 0.2 (25-27)             |
| DGO                          | 7.1±0.9 (6.5-7.8)        |                                |
| Tail length                  | 15.7±1.9 (14.3-17.1)     | 13.0 ± 0.1 (11-16)             |
| Excretory pore to head end   | 98.0±0.3 (97.8-98.3)     |                                |
| Body width at excretory pore | 20.1±2.4 (18.3-21.9)     |                                |
| V%                           | 64.2±0.6 (63.7-64.6)     | 64.0 ± 0.9 (62-66)             |
| a                            | 24.5±0.1 (24.4-24.6)     | 26.0 ± 1.1 (24-29)             |
| c                            | 39.3±0.0 (39.3-39.4)     | 48 ± 1.7 (44-50)               |
| c'                           | 1.0±0.0 (1.0-1.0)        | 48 ± 1.7 (44-50)               |

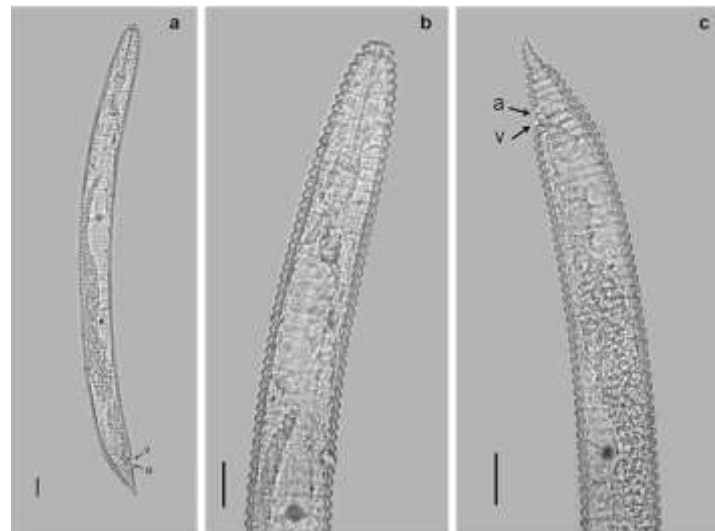


**Figure 5. Female of *Hemicriconemoides strictathecatus* Esser, 1960. (a): Entire body; (b): Anterior body (c): Posterior body; a: Anus; v: Vulva (Scale bar: 20 µm).**

**Table 3. Basic morphometric measurement values of *Hemicriconemoides strictathecatus* nematodes obtained from golf areas in Antalya province**

| Diagnostic Characters        | This Study<br>(n: 5 ♀)   | Van den Berg et al. (2014)<br>(n:15 ♀) |
|------------------------------|--------------------------|----------------------------------------|
| Body length                  | 507.1±16.7 (481.0-523.4) | 520±37.5 (475-607)                     |
| Body width                   | 33.5±2.9 (30.7-37.6)     |                                        |
| Body width at stylet base    | 29.2±2.3 (26.3-32.4)     |                                        |
| Body width at anus           | 20.1±2.0 (17.7-23.3)     |                                        |
| Stylet length                | 57.8±1.7 (54.9-59.2)     | 67±1.7 (64.5-69.5)                     |
| Tail length                  | 26.3±2.4 (23.8-29.8)     | 23±3.0 (18.5-28.5)                     |
| Excretory pore to head end   | 127.8±7.0 (121.2-136.0)  | 126±7.8 (116-142)                      |
| Body width at excretory pore | 33.0±2.4 (29.8-35.4)     |                                        |
| V%                           | 93.1±0.6 (91.8-93.7)     | 93±0.6 (91.5-94)                       |
| a                            | 15.1±1.1 (13.5-16.8)     | 16.4±1.8 (12.8-19.1)                   |
| c                            | 19.3±1.6 (17.0-21.4)     | 23±2.9 (17.2-27.1)                     |
| c'                           | 1.3±0.1 (1.1-1.4)        | -                                      |



### 3.3. *Hemicycliophora* de Man, 1921

Nematode individuals belonging to the genus *Hemicycliophora* were identified in twenty-eight samples (Table 1). For this reason, the most detected nematode genus in the golf areas is *Hemicycliophora* with a rate of 51.85%.

#### 3.3.1. *Hemicycliophora punensis* Darekar & Khan, 1980

*Hemicycliophora punensis* species belonging to the *Hemicycliophora* genus was detected in twelve samples in this study (Table 1). For this reason, this species is the most frequently detected species in the soil samples. The presence of the species in the sampled areas is 22.22% (Table 1). Morphometric measurement values of individuals of this species are given in Table 4. Body almost straight, cuticular sheath tightly fitting body, only adjacent to the labial and vulval region. *H. punensis* is characterized tail morphology (elongated, conoid or slightly offset spike with narrowly rounded terminus) and posteriorly located vulva (Figure 6).

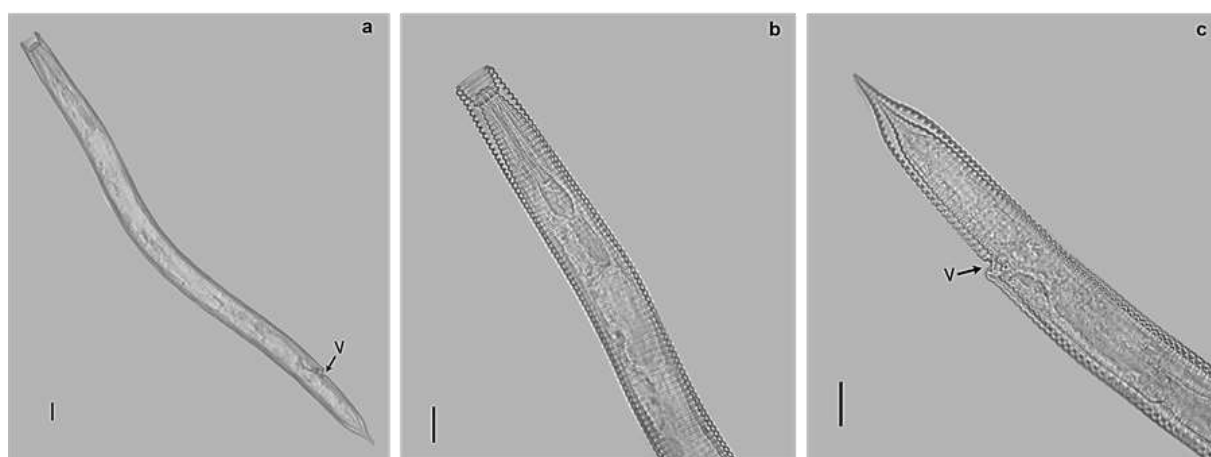


Figure 6. Female of *Hemicycliophora punensis* Darekar & Khan, 1980. (a): Entire body; (b): Anterior body (c): Posterior body; v: Vulva (Scale bar: 20  $\mu$ m).

Table 4. Basic morphometric measurement values of *Hemicycliophora punensis* nematodes obtained from golf areas in Antalya province

| Diagnostic Characters        | This Study<br>(n: 43 ♀)        | Darekar and Khan (1981)<br>(n:5 ♀) |
|------------------------------|--------------------------------|------------------------------------|
| Body length                  | 767.2 $\pm$ 54.7 (642.1-893.9) | 800-1000                           |
| Body width                   | 40.3 $\pm$ 3.0 (33.5-45.5)     | -                                  |
| Body width at stylet base    | 32.6 $\pm$ 2.0 (28.9-36.6)     | -                                  |
| Body width at anus           | 31.1 $\pm$ 2.0 (26.3-35.0)     | -                                  |
| Stylet length                | 69.113 $\pm$ 3.202 (59.7-77.9) | 56-70                              |
| Tail length                  | 94.7 $\pm$ 8.2 (77.6-110.7)    | -                                  |
| Excretory pore to head end   | 148.1 $\pm$ 12.4 (119.7-186.7) | -                                  |
| Body width at excretory pore | 38.2 $\pm$ 3.4 (31.7-51.3)     | -                                  |
| V%                           | 82.3 $\pm$ 1.8 (77.5-87.9)     | 80-90                              |
| a                            | 19.0 $\pm$ 1.7 (16.1-23.5)     | 19-25                              |
| c                            | 8.1 $\pm$ 0.5 (7.0-9.2)        | 5-7                                |
| c'                           | 3.0 $\pm$ 0.2 (2.4-3.7)        | -                                  |

#### 3.3.2. *Hemicycliophora iranica* Loof, 1984

Another species found in the samples in this study golf areas and belonging to the *Hemicycliophora* genus is *H. iranica*. This species was detected in four of the samples, whose occurrence frequency was determined as 7.40% (Table 1). The morphometric measurement values of this species, are given in Table 5. Body is almost straight as a result of fixation. The sheath fits tightly, with distinct annulation throughout. The lip region is formed by two annules, clearly visible on both the cuticle and sheath; it is truncate. The tail is initially cylindrical, with the distal part tapering, forming an elongated triangular shape, and the terminus is rounded (Figure 7).

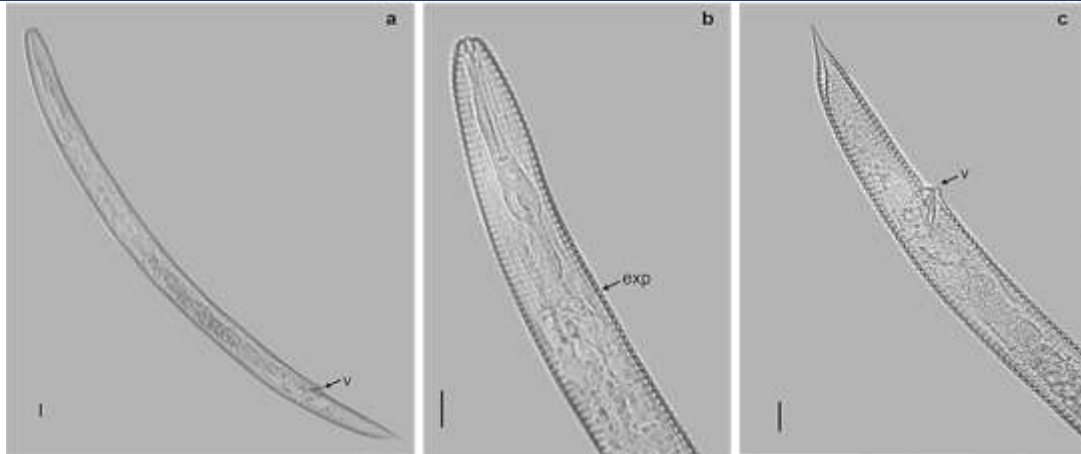


**Figure 7. Female of *Hemicycliophora iranica* Loof, 1984. (a): Entire body; (b): Anterior body (c): Posterior body; v: Vulva; exp: Excretory pore (Scale bar: 20 µm).**

**Table 5. Basic morphometric measurement values of *Hemicycliophora iranica* nematodes obtained from golf areas in Antalya province**

| Diagnostic Characters        | This Study<br>(n: 5 ♀)   | Loof (1984)<br>(n:25 ♀) |
|------------------------------|--------------------------|-------------------------|
| Body length                  | 825.7±31.0 (780.9-867.0) | 790-1030                |
| Body width                   | 41.5±2.7 (38.3-44.4)     | -                       |
| Body width at stylet base    | 30.4±3.4 (26.0-34.6)     | -                       |
| Body width at anus           | 30.9±4.6 (23.2-35.8)     | -                       |
| Stylet length                | 70.8±1.3 (69.4-73.1)     | 76-82                   |
| Tail length                  | 97.0±2.6 (93.8-99.2)     | 96.3-103                |
| Excretory pore to head end   | 151.7±10.2 (138.9-163.9) | -                       |
| Body width at excretory pore | 39.0±1.9 (36.2-40.3)     | -                       |
| V%                           | 80.5±0.6 (80.0-81.6)     | 82-86                   |
| a                            | 19.9±1.1 (18.5-21.3)     | 23-32                   |
| c                            | 8.5±0.5 (7.8-9.1)        | 8.2-10                  |
| c'                           | 3.2±0.5 (2.6-4.0)        | 3.4-4.1                 |

#### 4. Discussion

It is important to increase recreational areas to improve the quality of life in urban life. One of the most economically important of these areas is golf areas. However, agronomic problems may cause negativities in the performance of this sport. For this reason, the maintenance of turfgrass areas, which constitute a significant part of golf areas, is important. Yellowing, wilting, drying or inhomogeneous development observed in these areas are thought to be caused by irrigation frequency, grass type, nutrient deficiencies, disease or pests (Corwin et al., 2007; Ayanoğlu and Orta, 2019). However, PPNs can also cause significant damage in this golf and turfgrass areas. In addition, there are not many nematological studies in the turf and golf areas in Türkiye because the symptoms caused by PPNs are confused with damages caused by biotic and abiotic factors. In the previous study in golf areas, the presence of *Meloidogyne graminis* (Sledge & Golden, 1964) Whitehead, 1968 was reported for the first time in Türkiye (Uysal et al., 2023). In the present study, as a result of the morphological and morphometric analyzes performed on nematode individuals obtained from golf areas in Antalya province, the nematodes belonging to 11 genera from 3 orders were determined. Vandenbossche et al. (2011) identified PPNs belonging to 23 genera in grasslands. This diversity could be explained by different factors such as grass composition and land history. In this study, the most detected genus was *Hemicycliophora* spp., and the least detected ones were *Hoplolaimus* spp., *Aphelenchus* spp. and *Aphelenchoides* spp. The most detected species in the samples was *H. punensis* and the least one was *H. dihystra*. In studies conducted on grass fields in different countries, differences were observed in the most and least detected species (Walker et al., 2002; Vandenbossche et al., 2011). *Helicotylenchus*, *Mesocriconema*, *Trichodorus*, and *Tylenchorhynchus* spp. were reported as moderate concernare genera (Crow et al., 2020). These differences can be explained by geographical differences (Walker et al., 2002; Vandenbossche et al., 2011; Zeng et al., 2012; Dong et al., 2022). Also, in previous studies, it has been stated that nematodes belonging to the genera *Mesocriconema*, *Helicotylenchus*, *Hemicycliophora*, *Hoplolaimus*, *Paratrichodorus* and *Meloidogyne* are associated with both warm and cold season grasses (Walker et al.,

2002; Zeng et al., 2012). Similar to these results, in our study, nematode individuals belonging to the genera *Aphelenchoides*, *Aphelenchus*, *Cricconemella*, *Ditylenchus*, *Helicotylenchus*, *Hemicricconemoides*, *Hemicyclophora*, *Hoplolaimus*, *Longidorus*, *Paratrichodorus*, and *Tylenchus* were detected in the hot climate grasses that are more preferred in golf areas of Antalya province.

In this study, the nematode species and genera with very different characteristics have been detected. The high diversity in these nematodes indicate that they are not specific to the host plant (Zeng et al., 2012). Therefore, methods such as chemical, biological and biotechnical control should be included in the control program. In addition, no PPN species were detected in all 3 water samples and 8 of 51 soil samples. It is thought that the failure to detect any PPN species in these samples may be due to the observed seasonal fluctuations in PPN populations, as stated in previous studies (Jordan and Mitkowski, 2006; Zeng et al., 2012; McCurdy, 2023).

This study provides primary information about the genus-species diversity and distribution of PPNs found on golf courses and football pitches in Antalya, the largest golf tourism destination of Türkiye. However, beside the direct damage of the PPN species identified in this study, they may cause the damage together with soil-borne pathogens. As a matter of fact, it is known that PPNs increase the damage of soil-borne pathogens (Evans and Haydock, 1993; Göze Özdemir et al., 2023). However, detecting the presence of PPNs in grass areas is also important in terms of monitoring the contamination of new species. In addition, since it is the most comprehensive study ever conducted on golf courses in Antalya province and many PPNs were detected within the scope of this study, it will form the basis for future studies.

#### **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

#### **Conflict of Interest**

The authors have no conflicts of interest to declare that are relevant to the content of this article.

#### **Authorship Contribution Statement**

Concept: Mıstanoğlu, I., Uysal, G., Yılmaz, A., Gözel, U., Devran, Z.; Design: Mıstanoğlu, I., Yılmaz, A., Uysal, G., Arslan, E.C., Gözel, U., Devran, Z.; Data Collection or Processing: Mıstanoğlu, I., Yılmaz, A., Uysal, G., Arslan, E.C., Koca, M., Gözel, U., Devran, Z.; Literature Search: Mıstanoğlu, I., Yılmaz, A., Uysal, G.; Writing, Review and Editing: Mıstanoğlu, I., Uysal, G., Yılmaz, A., Gözel, U., Devran, Z.

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**Comparative Analysis of Deep Flow and Nutrient Film Technique in Vertical Farming****Dikey Tarımda Derin Akış ve Besleyici Film Tekniğinin Karşılaştırmalı Analizi****Temuçin Göktürk SEYHAN<sup>1\*</sup>, Sinem SEYHAN<sup>2</sup>****Abstract**

Unlike traditional agriculture, vertical farming systems utilize soilless cultivation methods. Various solid media cultures or hydroponic methods can be employed for soilless farming. The selection of methods and materials should be based on criteria such as economic feasibility, accessibility, sustainability, ease of use and management, as well as operating costs, efficiency, and quality. In these intensive production systems, it is crucial to design, establish, and operate them like a factory to maintain high profitability. Since plant growth and development in vertical farming are faster compared to other agricultural methods, all harvesting, planting, irrigation, and system maintenance operations need to be carried out promptly. Therefore, determining which method or methods are more efficient in these systems is highly important. For the widespread adoption and sustainability of vertical farming, analyses of different methods and systems are necessary. The aim of this study is to contribute to the literature on methods for vertical farming facilities. In this study, lettuce, rocket, cress, and dill were cultivated under controlled climatic conditions in a fully enclosed and computer-controlled laboratory using the Deep Flow Technique (DFT) and Nutrient Film Technique (NFT). The growth performance, yield characteristics, and quality parameters of the plants grown were compared between the two systems. For this comparison, total fresh weight, plant height and width, stem diameter, leaf count, discarded leaf count, and branching (in applicable species) were used. Additionally, the energy efficiency of the vertical farming systems established using the two techniques was evaluated. The energy use efficiency (EUE) of the NFT and DFT systems was calculated as 4.16 g kWh<sup>-1</sup> and 5.89 g kWh<sup>-1</sup>, respectively. The DFT system increased the total fresh weight and stem diameter in lettuce and dill plants by an average of 5%. Due to the higher biomass production in the DFT system, its EUE was calculated to be 5% higher.

**Keywords:** Nutrient film technique, Deep flow technique, Vertical farming, Energy use efficiency, Controlled environment agriculture

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## Öz

Geleneksel tarımdan farklı olarak dikey tarım sistemlerinde topraksız kültür yöntemleri kullanılmaktadır. Topraksız tarım için çeşitli katı ortam kültürleri veya su kültürü yöntemleri kullanmak mümkün olmaktadır. Yöntemlerin ve materyallerin seçimi, ekonomik uygunluk, erişilebilirlik, sürdürülebilirlik, kullanım ve yönetim kolaylığı gibi kriterlerin yanı sıra işletme maliyetleri, verimlilik ve kalite açısından değerlendirilerek yapılmalıdır. Bu tür yoğun üretim sistemlerinde, karlılığı yüksek tutmak için bir fabrika gibi planlamak, kurmak ve işletmek önemlidir. Dikey tarımda bitkilerin büyüme ve gelişmesi diğer tarım yöntemlerine göre daha hızlı olduğu için tüm hasat, ekim, sulama ve sistem bakım işlemlerinin hızlı bir şekilde yapılmasını gerektirir. Dolayısıyla bu sistemlerde hangi yöntem veya yöntemlerin daha verimli olduğu oldukça önemlidir. Dikey tarımın yaygınlaşması ve sürdürülebilir olması için farklı yöntemlere ve sistem analizlerine ihtiyaç duyulmaktadır. Bu çalışmanın amacı, dikey tarım tesisleri için bir yöntem literatürü oluşturulmasına katkı sağlamaktır. Bu çalışmada, tamamen kapalı ve bilgisayar kontrollü bir laboratuvarında, iklim parametrelerinin kontrol edildiği koşullarda, Derin Akış Tekniği (DFT) ve Besleyici Film Tekniği (NFT) kullanılarak marul, roka, tere ve dereotu bitki türleri yetiştirilmiştir. Yetiştirilen bitkilerin gelişim durumları, verim özellikleri ve kalite parametreleri her iki sistem arasında karşılaştırılmıştır. Bu karşılaştırma yapılırken toplam taze ağırlık, bitki boyu ve eni, gövde çapı, yaprak sayısı, ıskarta sayısı ve uygun bitki türlerinde dallanma sayısı kullanılmıştır. Ayrıca, iki farklı teknik kullanılarak kurulan dikey tarım sistemlerinin enerji verimliliği değerlendirilmiştir. NFT ve DFT sistemlerin enerji kullanım etkinliği sırasıyla 4.16 g kWh<sup>-1</sup> ve 5.89 g kWh<sup>-1</sup> olarak hesaplanmıştır. DFT sistemi marul ve dereotu bitkilerinde toplam taze ağırlığı ve gövde çapını ortalama %5 oranında artırmıştır. DFT sisteminde daha fazla biyokütle üretildiği için Enerji Kullanım Etkinliği (EUE) %5 daha yüksek olarak hesaplanmaktadır.

**Anahtar Kelimeler:** Besleyici film tekniği, Derin akış tekniği, Dikey tarım, Enerji kullanım etkinliği, Kontrollü ortam tarımı

## 1. Introduction

Vertical farming is a relatively new approach to agriculture that involves growing crops in vertically stacked layers in controlled environments such as greenhouses or indoor facilities (Anpo et al., 2019). Unlike traditional agriculture, which relies on fertile soil and favorable weather conditions, vertical farming uses advanced technologies such as hydroponics, aeroponics, and aquaponics to grow crops in a soilless medium, using artificial light sources and climate control systems to optimize plant growth (Şahin and Kendirli, 2016).

### 1.1. Hydroponic vertical farming

Hydroponic farming system components usually include growing containers, nutrient solutions, water and air pumps, lighting systems, pH sensors, EC sensors and a controller. These components work together to create an optimal growing environment for plants, allowing for efficient and productive agriculture (Niu and Masabni, 2022).

The primary objective of vertical farming is to maximize crop yields while minimizing the environmental impact of farming (Lubna et al., 2022). By using efficient space and resource management techniques, vertical farming can produce more food per unit area than traditional agriculture, consume less water and fertilizer, and generate less plant waste and carbon emissions.

Vertical farming has the potential to revolutionize the food industry, enabling year-round production of fresh, locally grown produce in urban areas, reducing the need for long-distance transportation of food, and creating new opportunities for small-scale farmers and entrepreneurs. However, there are also challenges associated with the high upfront costs of building and operating vertical farms, as well as the technical expertise required to maintain the complex systems involved (Seyhan, 2023).

In the forthcoming years, urban agriculture should focus on elements conducive to the sustainability of agricultural progress. Such elements encompass the allocation of space, the selection and diversity of crops cultivated and the integration of innovative technologies (Fitri et al., 2024).

#### 1.1.1. Nutrient film technique

NFT stands for “Nutrient Film Technique”, which is a hydroponic method used to cultivate plants. In an NFT system, plants are grown in a shallow stream of nutrient solution. The solution is pumped through a closed loop of plastic channels, and the roots of the plants are suspended in the solution stream. The nutrient film is extremely thin, usually around 5 millimeters deep (Resh, 2022).

One of the key advantages of NFT systems is that they use less water than other hydroponics methods, and because the roots are suspended in the solution, there is less risk of waterlogging, allowing for optimal oxygen levels for the roots. In addition, NFT systems can be used to cultivate a wide range of plants, including leafy vegetables, herbs, and some small fruiting plants, such as strawberries. Due to the nature of the system, it is generally not suitable for larger plants like fruit trees, but it can be effectively applied for ornamental plants or small-scale crops. This versatility makes NFT systems ideal for home gardens or small-scale commercial operations. (Alfredo, 2023).

NFT also has some limitations, one of the main ones being that the systems are often more fragile due to their reliance on continuous water flow and a thin nutrient film. Any interruptions, such as pump failures or power outages, can quickly deprive the water and nutrients, potentially causing stress or damage to the crops. Additionally, the channels can become clogged with debris or root growth, which may disrupt the flow of nutrients. As a result, water levels must be closely monitored to ensure plants receive the correct amount of water and nutrients. Inadequate water flow can lead to dehydration or nutrient deficiencies, especially in sensitive crops.

#### 1.1.2. Deep flow technique

DFT stands for “Deep Flow Technique”, which is another hydroponic method used to cultivate plants (Vimolmangkang et al., 2010). In a DFT system, plants are grown in a deep (usually 1-2 cm) water culture where the roots are suspended in a nutrient-rich solution. The solution is circulated using a pump, providing the plants with a constant supply of oxygen and nutrients. One of the key advantages of DFT systems is that they are more stable and fail-safe. DFT systems are relatively simple to set up and maintain and can be used to cultivate a wide range of plants, including leafy vegetables, herbs, and certain small fruiting plants like strawberries. DFT has shown

potential for sustainable food production in regions facing resource constraints. Efficient nutrient management in hydroponic systems, especially in DFT setups, plays a crucial role in optimizing crop yield and input use, including under resource-limited conditions (Majid et al., 2021).

However, due to the size and structural needs of larger plants, such as fruit trees, DFT systems are generally not suitable for them. They can also be effectively used for ornamental plants. It is important to ensure that the nutrient solution is properly balanced and that the pH levels are appropriate for the plants being grown.

## 2. Materials and Methods

The study was conducted in an indoor farming laboratory (2.80 m W × 4.20 m L × 2.60 m H) located at the Agricultural Machinery and Technologies Engineering Department, Ankara University, Turkey. The laboratory had automated controls for air conditioning, nutrient dosing, and lighting.

The air conditioning was programmed to cool the cultivation room to 16°C at night (1900h to 1000h) to simulate night chill. During the day, the temperature was maintained at 22°C. Plants were grown under a photosynthetic photon flux density (PPFD) of 265  $\mu\text{mol m}^{-2} \text{s}^{-1}$  provided by LED lights, which resulted in a daily light integral (DLI) of 15.3  $\text{mol m}^{-2}$  over a 16-hour photoperiod. Relative humidity in the cultivation room was controlled and maintained at 65–70% throughout the experiment.



**Figure 1. Hydroponic unit**

The hydroponic unit consisted of an opaque gray HDPE (High-Density Polyethylene) reservoir (60 liters), automated peristaltic dosing pumps for A and B nutrients and nitric acid (C), a main pump, PVC tubing, PVC NFT hydroponic channels and stainless steel DFT trays. The main pump (200 L h<sup>-1</sup> at 3.5 m head) delivered water continuously via 20 mm PVC pipes.

Tap water was filtered through a 5  $\mu\text{m}$  particle filter, an activated carbon filter, a 1  $\mu\text{m}$  particle filter and an R/O filter, respectively. The electrical conductivity (EC) of R/O output was measured as 0.012 dS m<sup>-1</sup>.

The hydroponic unit (0.60m W × 1.20m L × 2.0m H) had 4 layers with 3 plastic NFT channels (0.10m W × 1.20m L × 0.05m H) on each of the upper 2 layers and 1 stainless steel DFT tray (0.60m W × 1.20m L × 0.05m H) on each of the lower 2 layers. The upper NFT channels were interconnected for the nutrient solution transfer to the lower layers. Nutrient solution from the reservoir was supplied via a single pump (200 L h<sup>-1</sup> at 3.5 m head) and was transferred sequentially through the upper NFT channels, the lower NFT channels, and finally to the DFT trays, before returning to the reservoir, creating a recirculating system (Figure 1).

The depth of the nutrient film in the NFT channels was maintained at approximately 3–5 mm to ensure optimal aeration for the roots. In the DFT trays, the nutrient solution depth was maintained at 10–15 mm to provide sufficient root submersion while preventing waterlogging. The depth levels in DFT trays were controlled using raised overflow drains installed at each DFT layer, which ensured the nutrient solution did not exceed the set levels.

To ensure that both systems received a uniform nutrient composition, the recirculating system was closely monitored. The nutrient solution was continuously mixed within the reservoir using the circulation of the main pump. Regular measurements of electrical conductivity (EC) and pH were taken to confirm consistent nutrient delivery across all layers. Although the NFT system received the solution first, the design of the interconnected system ensured that nutrient depletion was minimal before the solution reached the DFT trays. This was further validated by consistent growth and morphological data across both systems.

Plant spacing was 20 cm in both directions. This resulted in a total of 72 plant growth holes (36 NFT and 36 DFT) (Figure 2). The vertical distance between plant growth holes and LEDs was 40 cm for both NFT and DFT.

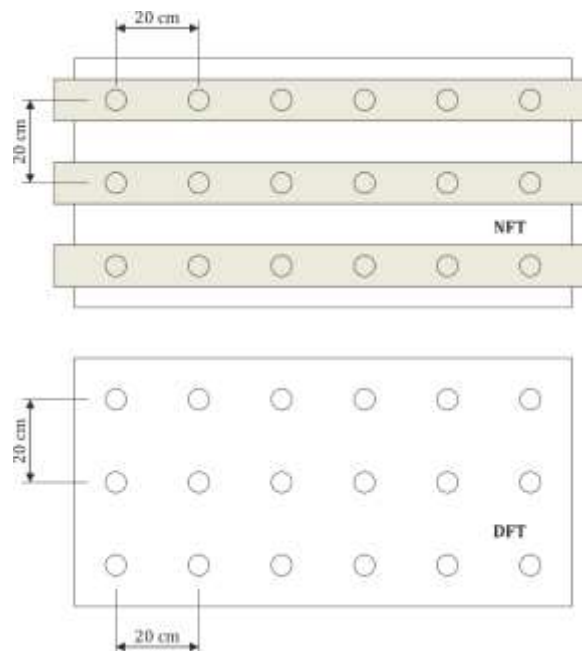


**Figure 2. NFT and DFT layers**

### 2.1. Plant material

The experiments were conducted with lettuce (*Lactuca sativa* L.), rocket (*Eruca vesicaria*), dill (*Anethum graveolens* L.) and cress (*Lepidium sativum*).

Plants were grown in a growth chamber from seed to transplant. Seeds were sown in Oasis® Horticubes® growing media, pre-soaked with 1.2 dS m<sup>-1</sup> nutrient solution. 1 seed per cube for lettuce and 10 seeds per cube for rocket, dill and cress were sown. Sowing multiple seeds in a single cube ensures that a sufficient number of plants germinate and grow together, creating a fuller, more marketable appearance suitable for culinary use. This method also helps mitigate the risk of uneven germination or growth issues in any single seed, ensuring that each cube produces a viable and marketable plant cluster. After germination, plantlets were moved under 150 μmol m<sup>-2</sup> s<sup>-1</sup> LED lights until transplantation. Plantlets were transplanted 15 days after sowing and harvested after 32 days in the main hydroponic unit. All plants experienced the same environmental conditions within the same growing room. At the end of each cultivation period, 3 plants out of 9 from NFT and DFT layers were selected randomly for morphological analysis.

### 2.2. Experimental design

This experiment was designed to compare NFT and DFT hydroponics methods in terms of plant yield, morphological attributes and energy use efficiency (EUE).

Plants were grown for 32 days under a PPFD of 265 μmol m<sup>-2</sup> s<sup>-1</sup> and 16 h photoperiod, reaching 15.3 mol m<sup>-2</sup>

Daily Light Integral (DLI).

65 W LED modules were used to illuminate the growth area. LED lights were manufactured on demand by SpectBee (Ankara, Türkiye). The spectrum of LED lights is shown in *Figure 3*. Each day, plants were replaced randomly to ensure equal light reception.

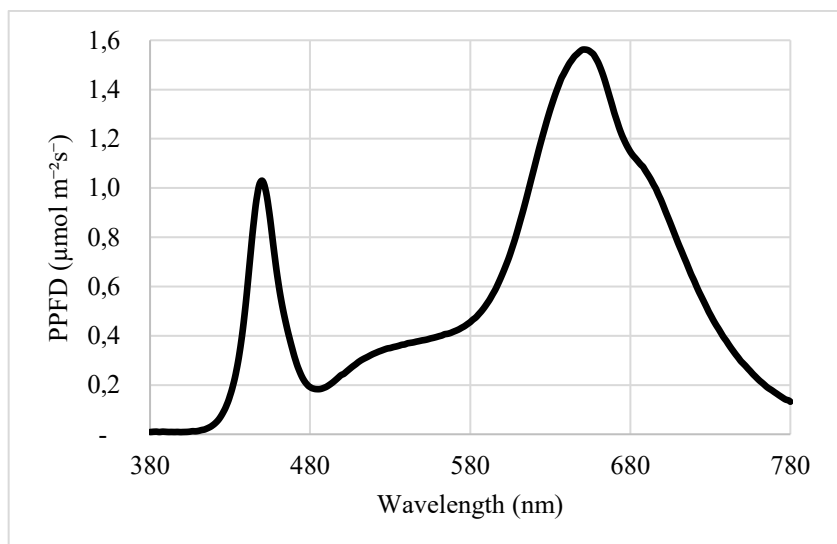


**Figure 3. Spectrum of LED lights**

Plants were fertigated with a nutrient solution (2.7 mM  $\text{NO}_3^-$ , 5.5 mM  $\text{K}^+$ , 1.6 mM P, 1.9 mM  $\text{Mg}^{2+}$ , 4.7 mM  $\text{Ca}^{2+}$ , 2.5 mM S, 71.6  $\mu\text{M}$  Fe, 1.5  $\mu\text{M}$  Zn, 46.3  $\mu\text{M}$  B, 1.6  $\mu\text{M}$  Cu, 1.6  $\mu\text{M}$  Mo, 9.1  $\mu\text{M}$  Mn and 0.6 mM  $\text{NH}_4^+$ ), with a target electrical conductivity of 1.9  $\text{dS m}^{-1}$  and pH of 6.5. Experiments were conducted in the laboratory in two consecutive cycles (*Table 1*).

All crops (lettuce, rocket, cress, and dill) were harvested on the same day, 32 days after transplantation, to ensure consistency in comparing growth and morphological parameters across both NFT and DFT systems. The decision to harvest on the same day was based on the experimental design, which aimed to evaluate the performance of the two hydroponic techniques under uniform conditions. While these crops might require different harvesting periods in a commercial setting, the fixed harvest day was chosen for experimental comparability under controlled conditions.

**Table 1. Experimental design**

| Stage                     | Date       |
|---------------------------|------------|
| First cycle sown          | 01.07.2022 |
| First cycle transplanted  | 15.07.2022 |
| Second cycle sown         | 22.07.2022 |
| First cycle harvested     | 05.08.2022 |
| Second cycle transplanted | 05.08.2022 |
| Second cycle harvested    | 19.08.2022 |

In the cultivation room, environmental conditions were carefully monitored and controlled to ensure uniformity across the experiment. The air temperature was maintained at 16 °C during the night (1900h to 1000h) and 22 °C during the day. Relative humidity was kept between 65% and 70%. A 3-day detailed chart of air and water temperature is given in *Figure 4*. The nutrient solution temperature was monitored to stay within the optimal range of 20–22 °C. The light was provided using LED modules at a PPFD of 265  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , resulting in a daily light integral (DLI) of 15.3  $\text{mol m}^{-2}$  with a 16-hour photoperiod. The electrical conductivity (EC) of the nutrient solution was maintained at 1.9  $\text{dS m}^{-1}$ , and pH levels were kept at 6.5 throughout the experiment.

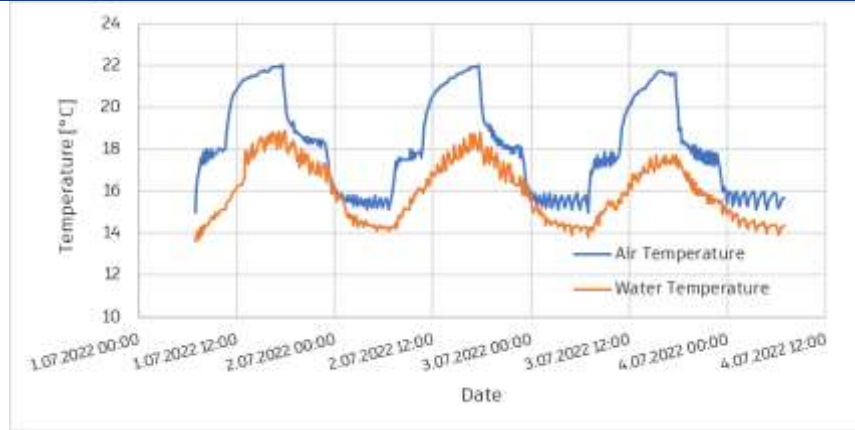


**Figure 4. 3-day air and water temperature of cultivation room**

Electrical conductivity (EC) was kept between 1.85 and 1.96 dS m<sup>-2</sup> for the experiment period (*Hata! Başvuru kaynağı bulunamadı.*).

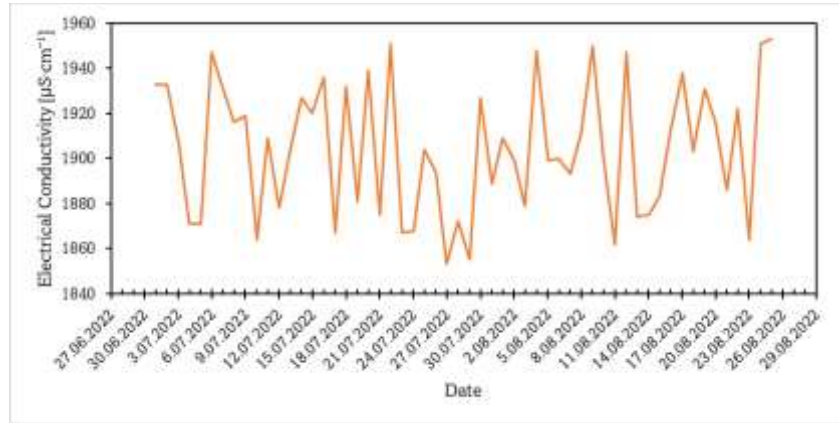


**Figure 5. Electrical conductivity of the nutrient solution**

### 2.3. Plant analysis

In this study, the development status, yield, and selected morphological attributes of lettuce, rocket, cress, and dill plants grown using the DFT and the NFT were compared. The selected morphological attributes were parameters such as total fresh weight, plant height, stem diameter, number of marketable leaves, and branching for herbs. However, chemical quality parameters such as nutrient content or antioxidant levels were not included in this study and could be the focus of future research.

The following analyses were done to collect plant morphological data:

*Total fresh weight (g):* Plants harvested with their roots from both hydroponics production systems were weighed together with their roots.

*Plant height (cm):* The distance between the root collar of the plants harvested from the systems and the highest point of the plant was determined.

*Plant width (cm):* The width of the harvested plants was measured. This analysis was only done for lettuce.

*Stem diameter (mm):* The stem diameter just above the root collar after harvest was measured.

*Number of marketable leaves (pieces/plant):* The marketable leaves of the plants were determined by counting the leaves in the marketable portion.

*Number of discarded leaves (pieces/plant):* The non-marketable leaves when the plants were harvested were determined.

*Branch per plant (pieces/plant):* Branches of the plant were counted. This analysis was only done for herbs.



## 2.4. Energy use efficiency

In this study, EUE was calculated based on the total biomass produced relative to the energy consumption of the system components, including LED lights, water pump, air pump, air conditioning, and automation systems. While this method provides a straightforward measure of energy efficiency specific to the hydroponic systems, we acknowledge that it does not account for additional input parameters such as human labor, nutrient costs, pest control, and other operational expenses. During the experiments, the total energy consumption of the LED lights, water pump, automation system and air conditioning was measured using a commercial electricity meter (Makel M550.2251, Makel, İstanbul, Türkiye). EUE was calculated by dividing total produced biomass by total energy consumption in cultivation duration (1) (Baran and Gökdoğan, 2017; Mohammadi et al., 2008; Pal et al., 2021).

$$EUE \left( \frac{g}{kWh} \right) = \frac{\sum \text{Produced Biomass (g)}}{\sum \text{Energy Consumption (kWh)}} \quad (\text{Eq.1})$$

## 2.5. Data analysis

To determine significant differences between the parameters measured in the two hydroponic systems (NFT and DFT), an analysis of variance (ANOVA) was applied. The significance level was chosen to be 0.05. Tukey's Honestly Significant Difference (HSD) test was applied to compare the two systems. Statistical analysis was conducted using JMP Pro 16 software.

## 3. Results and Discussion

### 3.1. Comparison of Systems Within a Shared Setup

The decision to compare the two systems within a single experimental setup was driven by the need to minimize the influence of environmental variability and focus solely on the performance differences between the systems. This approach ensured that both systems operated under identical, controlled conditions, including light intensity, temperature, relative humidity, and nutrient solution composition, thereby enabling a fair and direct comparison.

Advantages of This Approach:

- **Environmental Consistency:** By eliminating variations caused by differing environmental conditions, the results reflect only the differences inherent to the systems themselves.
- **Direct Comparison:** The shared setup allowed for direct performance comparisons between the systems under the same experimental conditions.

Limitations of This Approach:

- **Nutrient Solution Interaction:** Using a shared nutrient solution introduced the possibility of nutrient depletion in the first system (NFT) before reaching the second system (DFT). However, this was mitigated by continuous mixing of the solution and regular monitoring to maintain nutrient consistency.
- **Mixed Cropping Design:** The mixed-cropping approach may have limited each plant species' ability to reach its optimal growth potential, as different crops have varying nutrient and pH requirements.

Impact on Results:

This design successfully minimized environmental variability, providing a clearer assessment of system performance under shared conditions. However, it does not allow for independent evaluation of each system's performance when used alone. Therefore, the findings are specific to scenarios where the systems are integrated. Future studies should focus on evaluating the systems independently to provide a more comprehensive understanding of their individual performance under tailored conditions.

### 3.2. Yield and morphological comparison

Lettuce and herb production values for the NFT and DFT are represented in *Table 2*. The comparisons presented in the table are primarily focused on the performance of the same crop grown in two different hydroponic systems (NFT and DFT). For each crop (lettuce, rocket, dill, and cress), key parameters such as total fresh weight, plant height, stem diameter, and others were compared between the two systems. The statistical significance ( $P < 0.05$ ) applies to the comparison of the same crop between the two systems, as indicated by superscript letters (e.g.,

a, b). Total fresh weight of lettuce and dill was significantly ( $P < 0.05$ ) higher (67.85% and 72.4%, respectively) in DFT. Stem diameter of lettuce and dill were significantly higher (39.4% and 22.6%) in DFT. The number of marketable leaves of lettuce was significantly higher (34.5%) in DFT.

**Table 2. Yield and morphological comparison of Lettuce, Rocket, Dill, and Cress grown in NFT and DFT systems**

|                                         | Lettuce                   |                            | Rocket                    |                           | Dill                      |                           | Cress                     |                           |
|-----------------------------------------|---------------------------|----------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
|                                         | NFT                       | DFT                        | NFT                       | DFT                       | NFT                       | DFT                       | NFT                       | DFT                       |
| <b>Total fresh weight (g)</b>           | 74.57 <sup>b</sup> ± 2.49 | 124.73 <sup>a</sup> ± 4.15 | 36.58 <sup>a</sup> ± 0.41 | 31.67 <sup>a</sup> ± 0.72 | 8.60 <sup>b</sup> ± 0.36  | 14.83 <sup>a</sup> ± 0.50 | 7.96 <sup>a</sup> ± 0.16  | 9.60 <sup>a</sup> ± 0.15  |
| <b>Plant height (cm)</b>                | 18.40 <sup>a</sup> ± 0.71 | 17.83 <sup>a</sup> ± 0.89  | 29.33 <sup>a</sup> ± 0.98 | 32.00 <sup>a</sup> ± 1.25 | 31.33 <sup>a</sup> ± 1.09 | 34.00 <sup>a</sup> ± 0.82 | 20.67 <sup>a</sup> ± 0.27 | 23.00 <sup>a</sup> ± 1.70 |
| <b>Plant width (cm)</b>                 | 23.70 <sup>a</sup> ± 1.19 | 26.00 <sup>a</sup> ± 0.82  | -                         | -                         | -                         | -                         | -                         | -                         |
| <b>Stem diameter (mm)</b>               | 10.97 <sup>b</sup> ± 0.22 | 15.29 <sup>a</sup> ± 0.73  | 10.86 <sup>a</sup> ± 0.59 | 12.70 <sup>a</sup> ± 0.49 | 7.00 <sup>b</sup> ± 0.06  | 8.58 <sup>a</sup> ± 0.22  | 6.22 <sup>a</sup> ± 0.28  | 7.04 <sup>a</sup> ± 0.60  |
| <b>Marketable leaves (pieces/plant)</b> | 19.33 <sup>b</sup> ± 0.27 | 26.00 <sup>a</sup> ± 1.70  | -                         | -                         | -                         | -                         | -                         | -                         |
| <b>Discarded leaves (pieces/plant)</b>  | 2.33 <sup>a</sup> ± 0.54  | 2.67 <sup>a</sup> ± 0.72   | -                         | -                         | -                         | -                         | -                         | -                         |
| <b>Branch per plant</b>                 | -                         | -                          | 7.33 <sup>a</sup> ± 0.54  | 8.33 <sup>a</sup> ± 0.27  | 6.00 <sup>a</sup> ± 0.00  | 6.33 <sup>a</sup> ± 0.27  | 7.33 <sup>a</sup> ± 0.27  | 7.33 <sup>a</sup> ± 0.54  |

<sup>a, b</sup>: Values showing the same letter are not significant ( $P > 0.05$ )

\*The data in the table are presented as mean ± standard deviation (SD)

The results of current trials demonstrated that the DFT system supported the plant growth in terms of total fresh weight and stem diameter for lettuce and dill.

Our findings are consistent with those of Nurza (2022), who observed that DFT systems significantly enhanced the growth of water spinach compared to NFT systems. This is attributed to the slower water flow in DFT, which allows for better nutrient absorption.

### 3.3. Energy use efficiency

Daily energy usages of various consumers are given in Table 3.

**Table 3. Distributed energy usage of consumers**

| Consumer         | Energy consumption (kWh day <sup>-1</sup> ) | Percentage     |
|------------------|---------------------------------------------|----------------|
| LED lights       | 6.24                                        | 72.22%         |
| Air pump         | 0.11                                        | 1.27%          |
| Water pump       | 0.32                                        | 3.70%          |
| Air conditioning | 1.42                                        | 16.44%         |
| Automation       | 0.55                                        | 6.37%          |
| <b>TOTAL</b>     | <b>8.64</b>                                 | <b>100.00%</b> |

Power consumption of air pump, water pump, air conditioning, and automation was divided between the two subsystems (NFT and DFT). Total biomass production of the NFT system (lettuce and herbs together) was 1.149.39 g at the end of 32-days production cycle. The total biomass production of the DFT system was 1,627.47 g. EUE of both systems in this study were calculated as 4.16 g kWh<sup>-1</sup> for NFT and 5.89 g kWh<sup>-1</sup> for DFT, which are relatively lower compared to the literature. For instance, Gillani et al. (2023) reported an EUE of 31.3 g kWh<sup>-1</sup> for the NFT system and 24.53 g kWh<sup>-1</sup> for the Deep-Water Culture (DWC) system, with the NFT system outperforming DWC. The lower EUE values in our study can be attributed to the type of crops grown. Unlike Gillani et al. (2023), where lettuce was the sole crop, this study included lightweight herbs such as rocket, dill, and cress alongside lettuce, resulting in lower overall biomass production and consequently, reduced EUE.

#### 4. Conclusions

This study demonstrated that the Deep Flow Technique (DFT) generally outperformed the Nutrient Film Technique (NFT) in terms of total fresh weight and stem diameter for lettuce and dill, while similar performance was observed for rocket and cress. The higher biomass production in DFT also resulted in a 5% improvement in energy use efficiency (EUE) compared to NFT. These findings suggest that DFT systems may offer advantages for crops with greater water and nutrient uptake requirements.

The two systems were compared within the same experimental setup to minimize the effects of environmental variability and focus solely on system performance. This approach ensured that both systems were tested under identical conditions, including light intensity, temperature, relative humidity, and nutrient solution composition, enabling a fair and direct comparison. However, a limitation of this approach is the shared use of the nutrient solution, which may have introduced interactions between the systems. Specifically, the NFT system received the solution first, potentially affecting the nutrient homogeneity of the DFT system. Nonetheless, continuous mixing and regular monitoring of the nutrient solution helped mitigate this issue.

Additionally, the mixed-cropping design and the unified nutrient solution may have limited the potential of each crop to reach its optimal growth performance. Future studies should explore crop-specific nutrient management and mono-cropping systems to provide a more detailed understanding of the advantages and limitations of each hydroponic method. Lennard and Ward (2019) compared the NFT hydroponic system with the NFT aquaponic system in terms of plant growth rates. Researchers used lettuce, dill, rocket, coriander, and parsley as plant materials. They used commercial nutrient solutions for hydroponics and fish waste for aquaponics. Researchers found that both systems produce plants with equal quality. Lennard and Leonard (2006) found that DFT systems produced 0.34 kg m<sup>-2</sup> more lettuce (*Lactuca sativa* L.) than NFT systems did, parallel to our research.

These results align with prior research highlighting the economic feasibility and productivity advantages of DFT systems. For instance, Afriyanti et al. (2024) demonstrated that DFT systems achieved a 16.9% ROI and a payback period of 5.89 years, compared to NFT systems with a 10.9% Return on Investment (ROI) and a payback period of 9.13 years. This emphasizes the potential of DFT systems not only in terms of biomass production but also in economic efficiency for hydroponic lettuce farming.

This study reinforces the potential of hydroponic systems like DFT and NFT to address challenges in urban agriculture. As noted by Indriani et al. (2022), these systems offer an effective means of producing high-quality crops in limited spaces while ensuring resource sustainability. This study highlights the trade-offs between DFT and NFT systems. As noted by Fukuyama (1990), while DFT is advantageous for maximizing fruit size, NFT systems excel in producing crops with higher sweetness and texture, emphasizing the importance of system selection based on target quality attributes.

Our findings suggest that the performance of hydroponic systems like NFT and DFT is highly crop-specific and influenced by experimental conditions. While Manggala et al. (2023) reported superior results for NFT systems in Caisim production, our study demonstrates that DFT systems may offer advantages for mixed cropping and crops with higher nutrient demands. This highlights the importance of tailoring hydroponic system design to the specific needs of the crop and growing environment.

These results provide valuable insights for optimizing vertical farming systems, particularly for environments where energy efficiency and resource conservation are critical. Future research could focus on independent evaluations of each system under tailored conditions to enhance our understanding of their standalone performance.

#### Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

#### Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

#### Authorship Contribution Statement

Concept: Seyhan, T. G., Seyhan, S.; Design: Seyhan, S.; Data Collection or Processing: Seyhan, S.; Statistical Analyses: Seyhan, T. G.; Literature Search: Seyhan, T. G., Seyhan, S.; Writing, Review and Editing: Seyhan, T. G., Seyhan, S.

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**Effects of Iso-Osmotic Potential of NaCl and PEG<sub>6000</sub> Solutions on Germination and Initial Seedling Growth of Sweet White Lupin (*Lupinus albus* L)**

İzo-Ozmotik NaCl ve PEG<sub>6000</sub> Solüsyonlarının Tatlı Beyaz Acı Baklanın (*Lupinus albus* L.) Çimlenme ve İlk Fide Gelişimi Üzerine Etkileri

Ramazan BEYAZ<sup>1\*</sup>, Veli Vural USLU<sup>2</sup>

**Abstract**

Sweet white lupin has a growing importance as a staple crop due to its rich protein and mineral content. Investigation of unfavorable environmental conditions at the seedling stage is critical for understanding and overcoming the challenges during germination and initial growth. In this study, the effects of salt and drought stress were investigated upon induction of NaCl and PEG<sub>6000</sub> osmotic agents at iso-osmotic potential (0, -0.3 and -0.6 MPa) on seed germination and initial seedling growth in sweet white lupin (*Lupinus albus* L.). The research was carried out for 21 days under laboratory conditions according to a completely randomized plot design with 4 replicates. In order to assess the growth upon stress, germination percentage, mean germination time, germination rate index, shoot and root length, root/shoot length, shoot and root fresh weight, shoot and root dry weight, shoot and root dry matter content, root/shoot dry matter content, shoot and root water content and seedling vigor index parameters were measured. The results demonstrated that NaCl and PEG<sub>6000</sub> solutions applied at the same osmotic potential had statistically significant effects on the measured germination and growth parameters. PEG<sub>6000</sub> treatments at the same osmotic potential had more adverse effects on germination and initial seedling growth than NaCl treatments. In addition, shoot growth was more adversely affected than root growth in PEG<sub>6000</sub> and NaCl treatments. The germination was limited in -0.6 MPa PEG<sub>6000</sub> treatment and no subsequent seedling growth was observed. In this study, we documented that the white lupine's tolerance to drought during germination and initial seedling growth periods was lower than salinity at the same iso-osmotic potential and saline and arid soils showing an osmotic water potential of -0.6 MPa (12.7 dS m<sup>-1</sup> EC and 22% PEG<sub>6000</sub>) are inhibitory for lupin germination and growth. This study lays the ground for further physiological and molecular studies on the effects of salt and osmotic stress on white lupins.

**Keywords:** *Lupinus albus* L., Iso-osmotic potential, NaCl, PEG<sub>6000</sub>, Germination, Initial seedling growth

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## Öz

Tatlı beyaz acı bakla, zengin protein ve mineral içeriği nedeniyle temel bir ürün olarak giderek artan bir öneme sahiptir. Fide aşamasında elverişsiz çevre koşullarının araştırılması, çimlenme ve erken büyüme sırasındaki zorlukların anlaşılması ve üstesinden gelinmesi için kritik öneme sahiptir. Bu çalışmada, tatlı beyaz acı baklada (*Lupinus albus* L.) tohum çimlenmesi ve ilk fide büyümesi üzerine NaCl ve PEG<sub>6000</sub> ozmotik ajanlarının izo-ozmotik potansiyelde (0, -0,3 ve -0,6 MPa) indüksiyonu ile oluşturulan tuz ve kuraklık stresinin etkileri araştırılmıştır. Araştırma, tesadüfi parseller deneme desenine göre 4 tekerrür olacak şekilde laboratuvar koşullarında 21 gün boyunca yürütülmüştür. Stres altındaki büyümeyi değerlendirmek amacıyla çimlenme yüzdesi, ortalama çimlenme süresi, çimlenme indeksi, sürgün ve kök uzunluğu, kök/sürgün oranı, sürgün ve kök taze ağırlığı, sürgün ve kök kuru ağırlığı, sürgün ve kök kuru madde içeriği, kök/sürgün kuru madde içeriği, sürgün ve kök su içeriği ve fide canlılık indeksi parametreleri ölçülmüştür. Sonuçlar, aynı ozmotik potansiyelde uygulanan NaCl ve PEG<sub>6000</sub> çözeltilerinin ölçülen çimlenme ve büyüme parametreleri üzerinde istatistiksel olarak anlamlı etkilere sahip olduğunu göstermiştir. Aynı ozmotik potansiyelde PEG<sub>6000</sub> uygulamaları, NaCl uygulamalarına kıyasla çimlenme ve ilk fide büyümesi üzerinde daha olumsuz etkilere sahip olmuştur. Ayrıca, PEG<sub>6000</sub> ve NaCl uygulamalarında sürgün büyümesi kök büyümesine kıyasla daha olumsuz etkilenmiştir. Çimlenme -0.6 MPa PEG<sub>6000</sub> uygulamasında sınırlı kalmış ve sonuç olarak fide büyümesi gözlenmemiştir. Bu çalışmada, tatlı beyaz acı baklanın çimlenme ve ilk fide büyüme dönemlerinde kuraklığa karşı toleransının, aynı izo-ozmotik potansiyeldeki tuzluluktan daha düşük olduğunu ve -0.6 MPa (12,7 dS/m EC ve %22 PEG<sub>6000</sub>) ozmotik su potansiyeli gösteren tuzlu ve kurak toprakların acı bakla çimlenmesi ve büyümesi için engelleyici olduğunu belgelenmiştir. Bu çalışma, tuz ve ozmotik stresin beyaz acı bakla üzerindeki etkileri konusunda daha ileri fizyolojik ve moleküler çalışmalar yapılmasına zemin hazırlamaktadır.

**Anahtar Kelimeler:** *Lupinus albus* L., İzo-ozmotik potansiyel, NaCl, PEG<sub>6000</sub>, Çimlenme, İlk fide büyümesi



## 1. Introduction

Drought and salinity are two of the the most critical agricultural environmental challenges worldwide and the consequences are likely to worsen in the course of current climate change (Giordano et al., 2021). The negative impacts of water scarcity and high salinity on plants can be seen at the whole-plant level as plant mortality and/or decreased yield (Zheng et al., 2010). High salinity decreases plants' water uptake capacity, leading to a rapid decline in growth rate and triggering a set of metabolic changes similar to those induced by water stress (Munns, 2002). Accumulation of soluble salts in soils increases the osmotic pressure of the soil solution, potentially impeding water absorption by seeds or plant roots. Salt damage to plants is caused by reduced water availability, toxicity of certain ions, and nutritional imbalance resulting from these ions (Murillo-Amador et al., 2002).

Salt stress arises from the accumulation of elevated concentrations of  $\text{Cl}^-$  or  $\text{Na}^+$  ions in the soil, resulting in ion toxicity in plants. While plant reactions to salinity differ among species, excessive absorption of  $\text{Na}^+$  typically results in nutritional imbalance. The  $\text{Na}^+$  ion reaches lethal concentrations before the  $\text{Cl}^-$  ion. Elevated concentrations of  $\text{Na}^+$  ions adversely affect photosynthetic activity and may exacerbate outcomes in salt-sensitive plants. Although  $\text{Na}^+$  ions may have detrimental effects on certain plants,  $\text{Cl}^-$  ions may be even more harmful in species such as soybeans and citrus. Chloride ions ( $\text{Cl}^-$ ) can impair photosynthetic activity and may induce ion toxicity in plants, similar to sodium ions ( $\text{Na}^+$ ). In reaction to ion toxicity, the plant-produced hormone abscisic acid (ABA) is crucial. The synthesis rate escalates during stress to avert disturbances in cellular growth and development systems (Yildiz et al., 2020). Certain ions must be present within plant cells for growth. Despite the presence of ions such as nitrogen, potassium, and calcium in the soil, their entry into plant cells is impeded by competition with other ions at elevated quantities. The presence of excessive concentrations of salt in soil hinders the absorption of ions essential for plant development. Plants initiate several reactions to mitigate this adverse effect and maintain low ion concentrations. Distributing ions for plant addition rather than allowing cellular absorption simultaneously is regarded as a crucial action for plant growth and development. The cell membrane is crucial for sustaining low ion concentrations during transit to plants. Proteins, channel proteins, and symporters facilitate the transport of ions into the plant. Antiporters are utilized in transport mechanisms. These transporters are situated in vacuolar membranes. V-ATPases are recognized as essential channels for plant survival under saline stress. The excessive concentration of  $\text{Na}^+$  ions in the soil prompts their movement into the cytoplasm, where they are transported to vacuoles via  $\text{Na}^+/\text{H}^+$  antiporters. In plant cell metabolism, another function is the maintenance of cytoplasmic  $\text{K}^+$  homeostasis. In the presence of salinity, the concentration of  $\text{K}^+$  experiences a significant reduction.  $\text{K}^+$  ions, which can be transported into cells via  $\text{K}^+$  transporters and membrane channels, exhibit low concentrations during salinity stress. An essential element in cell recruitment exists. When extracellular  $\text{K}^+$  concentration is low,  $\text{K}^+$  transporters facilitate high-affinity  $\text{K}^+$  absorption processes, which are activated when extracellular  $\text{K}^+$  concentration is elevated. Consequently, the concentration of  $\text{Na}^+$  ions escalates in saline conditions, leading to  $\text{Na}^+$  competing with  $\text{K}^+$  and diminishing  $\text{K}^+$  uptake into the cell. Increased  $\text{K}^+$  retention in the roots of plants such as wheat, maize, and beans has been identified as a method employed by these plants to endure salt stress. The accumulation of  $\text{K}^+$  ions in cells rises under salinity stress (Yildiz et al., 2020).

However, water deficit causes other damaging effects on plant growth including epinasty, stomatal closure, and decreased photosynthesis (Lei et al., 2021). In addition, these environmental factors cause osmotic imbalance in plants by lowering the water potential of their environment. Osmotic stress causes cell elongation to be inhibited, stomata to close, photosynthetic activity to be reduced, abnormalities in water and ion intake, assimilate translocation, and changes in numerous metabolic activities (Çakmakçı and Dallar, 2019; Darko et al., 2019). PEG is primarily utilized to obtain data from plants concerning drought stress. PEG is unable to permeate the plant cell wall and possesses a higher molecular weight than the other osmotic agents employed, particularly PEG<sub>6000</sub>. Consequently, it is often employed in germination and drought studies to regulate osmotic potential (Beyaz, 2023). Drought and salinity are the key environmental conditions that limit crop establishment success, and seed germination is the first important and most sensitive stage in the life cycle of plants (Benlioglu and Ozkan, 2020; Zuffo et al., 2020).

Lupins are a significant economic crop, and their seeds are a key part of animal feed. Especially sweet white lupins gained further economic importance due to their increasing role in human nutrition. Through their symbiotic relationship with  $\text{N}_2$ -fixing bacteria, they also play a critical part in maintaining long-term soil fertility. Lupins are

normally grown on well-drained acidic to neutral soils and are native to the Mediterranean region. Among the main obstacles to lupin production are drought and soil-related challenges including salt and nitrogen deficit (Yu and Rengel, 1999). There are limited reports about the responses of *L. albus* to salinity (Yu and Rengel, 1999; Fernandes et al., 2004; Slabu et al., 2010; Hussien, 2022) and drought (Yu and Rengel, 1999; Perisse et al., 2002; Pinheiro et al., 2004; Slabu et al., 2010; Annicchiarico et al., 2018; Pecetti et al., 2023). However, the effects of salt and drought stress at the iso-osmotic potential concentrations on germination and initial seedling growth of *L. albus* remain elusive. Therefore, the aim of this study is to determine and compare the responses of *L. albus* L. under iso-osmotic drought and salt stress conditions.

## 2. Materials and Methods

### 2.1. Seed Materials

*Lupinus albus* L. seeds (2023) were obtained from RLP AgroScience GmbH (Germany) were used as plant material in the study. This study was carried out at Kırşehir Ahi Evran University (Türkiye), Faculty of Agriculture, Department of Agricultural Biotechnology.

### 2.2. Preparation of iso-osmotic potential test solution with NaCl and PEG<sub>6000</sub>

Test solutions were prepared according to Kaya et al. (2006) and Li et al. (2011) using distilled water. Accordingly, briefly, 3.5 and 7.1 g of NaCl (Coons et al., 1990) were added to 1 liter of distilled water to prepare -0.3 MPa (=60 mM) and -0.6 MPa (=121 mM) NaCl osmotic potential solution, respectively. To prepare -0.3 MPa and -0.6 MPa PEG osmotic potential solution, 151.4 and 223.6 g of PEG (Michel and Kaufmann, 1973) were added to 1 liter of distilled water, respectively. The electrical conductivity (EC) values of NaCl solutions were 6.5 and 12.7 dS m<sup>-1</sup> as reported by Kaya et al. in 2006. Distilled water (0 MPa) was used as control.

### 2.3. Germination tests and morphological observations

With 10 ml of each test solution, three duplicates of 10 seeds were planted between three rolls of filter paper. Before planting, seeds were given a fungicide treatment (Thiram 80%), and papers were changed every two days to minimize the buildup of NaCl and PEG<sub>6000</sub> concentrations (Rehman et al., 1996). To prevent moisture loss, the rolled paper with seeds was placed in sealed, clear plastic bags. For 21 days, seeds were allowed to germinate at 20 ± 1°C degrees (Perisse et al., 2002) in the dark in incubator (Memmert-In110). The radicles were deemed to have germinated when they reached a length of ~ 2 mm. For ten days, the germination percentage was tracked every 24 hours (Şehirali and Yorgancılar, 2011).

Equation -germination percentage (GP) = (Number of germinating seeds/ Total number of seeds) × 100 (Eq. 1) (Al-Enezi et al., 2012)-was used to calculate the proportion of seeds that germinated after being subjected to drought stress.

To assess the rate of germination, the mean germination time (MGT) was determined (Ellis and Roberts, 1980).

$$MGT = \sum Dn / \sum D \quad (\text{Eq. 2})$$

where n is the number of freshly germinated seeds on day D, and D is the number of days since the start of the experiment. The germination rate index (speed of germination index) was calculated using the formula according to Maguire (1962) (Eq 3.)

$$GRI = \sum \text{No of Germinated Seeds} / \sum \text{No of Days} \quad (\text{Eq 3.}).$$

Seedlings with stunted primary roots and short, thick, spiral-shaped hypocotyls were deemed to have aberrant germination. Initial seedling growth parameters (shoot and root length, shoot and root fresh weights, shoot and root dry weights, shoot and root dry matter, shoot and root water content, and seedling vigor index) were measured after the 21<sup>th</sup> day. Samples were dried in an oven at 70°C for 48 hours before dry weights were calculated (Beyaz et al., 2011). The following parameters were used to calculate the growth parameters.

$$\text{Water content (WC)} = (\text{fresh weight} - \text{dry weight}) / \text{fresh weight} \times 100 \quad (\text{Zheng et al., 2008}) \quad (\text{Eq. 4})$$

$$\text{Dry matter (DM)} = (\text{dry weight} / \text{fresh weight}) \times 100 \quad (\text{Bres et al., 2022}) \quad (\text{Eq. 5})$$

$$\text{Seedling vigor index (SVI)} = (\text{average root length} + \text{average hypocotyl length}) \times \text{germination percentage (GP)} \quad (\text{Abdul-Baki and Anderson, 1973}) \quad (\text{Eq. 6})$$

## 2.4. Data Analysis

The experiment was set up a completely randomized plot experimental desing, with 4 repetitions per treatment and 20 seeds in each repitation. The percentage data underwent Arcsine transformation before being analyzed using One-way analysis of variance in the SPSS statistical tool (Version 22) (Snedecor and Cochran, 1967). The Duncan's Multiple Range Test (DMRT) was utilized to compare the mean differences at a significance level of  $P \leq 0.05$ .

## 3. Results and Discussion

In this study, the effects of different levels of salt and drought stress using NaCl and PEG<sub>6000</sub> osmotic agents at the same osmotic potential on seed germination and initial seedling growth in *L. albus* were investigated.

### 3.1. Effects of NaCl and PEG<sub>6000</sub> solutions at the same osmotic potential on germination

The seeds were germinated in different NaCl and PEG<sub>6000</sub> solutions. A stronger inhibition of germination and growth inhibition was readily observable in higher NaCl and PEG<sub>6000</sub> solutions (*Figure 1*). Germination percentage (GP -except NaCl treatments-), mean germination time (MGT) and germination rate index (GRI) were significantly ( $P \leq 0.01$ ) affected in both treatments. Depending on decreasing osmotic potentials of NaCl solutions, although GP did not change, the MGT increased and GRI decreased. When the control group (0 MPa) was compared with the highest NaCl solution (-0.6 MPa), there was an 8.76% increase in MGT and a 37.64% decrease in GRI (*Table 1*). However, with the decreasing osmotic potential of PEG<sub>6000</sub> solutions, GP and MGT increased, but GRI decreased. Compared to the control, GP and GRI reduced by 66.67% and 91.92% under -0.6 MPa PEG<sub>6000</sub> treatment. On the other hand, MGT increased by 39.45% under -0.6 PEG<sub>6000</sub> solution (*Table 2*). Salinity and drought affect plants with different mechanisms and plants respond differently to these stress factors. The effects of salt and drought stress on germination in plants occur in two ways. Salt stress both creates stress by limiting the osmotic potential of water and causes ion toxicity (Demir and Mavi, 2008). Drought stress, on the other hand, has an adverse effect by limiting the osmotic potential of water. In general, when the effects of NaCl and PEG<sub>6000</sub> applied at the same osmotic potential on germination in *L. albus* were examined in this study, it was seen that PEG<sub>6000</sub> treatments representing drought had more adverse effects than NaCl treatments representing salinity. Similar to these results, Li et al. (2011) reported that at the same osmolarity the inhibition of germination of pyrethrum (*Tanacetum cinerariifolium*) by PEG was stronger than by NaCl. Kaya et al. (2006) stated that inhibition of germination of sunflower (*Helianthus annuus* L.) at the same water potential of NaCl and PEG resulted from osmotic effect rather than ion toxicity. Murillo-Amador et al. (2002) revealed that salt (NaCl) stress had a lower effect on cowpea (*Vigna unguiculata* L. Walp.) seed germination in terms of the germination rate, the emergence rate, and the final germination and emergence percentage than water stress induced by PEG<sub>8000</sub> at the same osmotic potentials. Moreover, Yagmur and Kaydan (2008) reported that the adverse effect of PEG<sub>6000</sub> was higher than NaCl on germination percentage of triticale (*Triticosecale Witm.*, cv. Presto) at the same osmolarity. Other researchers also reported that PEG had a more adverse effect on germination than NaCl at the same osmolarity (Khajeh-Hosseini et al., 2003; Demir and Mavi, 2008; Moosavi et al., 2009; Tavares et al., 2021). NaCl and PEG at the same osmotic potentials reduced water absorption in seeds, but PEG showed a more pronounced effect in this reduction, indicating that ion uptake and osmotic adjustment occurred in seeds treated with NaCl solutions (Murillo-Amador et al., 2002).

### 3.2. Effects of NaCl and PEG<sub>6000</sub> solutions at the same osmotic potential on seedling growth

In 21 day old seedlings, we observed that both NaCl and PEG<sub>6000</sub> applied at different osmotic potentials affected the shoot and root growth parameters significantly differently (except root to shoot, root dry matter, and root water content) (*Table 1,2,3,4,5,6*). Compared to the control group, there was a decrease in shoot and root length due to the NaCl and PEG<sub>6000</sub> solutions at reduced osmotic potential. Compared to the control, there was a decrease of 40.09% and 44.58% for shoot and root in the NaCl treatment at -0.3 MPa osmotic potential, while there was a decrease of 89.08% and 44.45% for shoot and root in the PEG<sub>6000</sub> treatment at the same osmotic potential. No measurement could be made in the PEG<sub>6000</sub> treatment at -0.6 MPa osmotic potential for shoot and root. Therefore, it was observed that PEG<sub>6000</sub>, i.e. drought stress, had more adverse effects than NaCl treatments, i.e. salt stress, in terms of root and shoot growth. In several plant organs, an increase in the expression, activity, and/or concentration of aquaporins, commonly referred to as aquaporin water channels, has been noted in response to NaCl, but not to PEG, which is positively correlated with the reduced sensitivity of seeds to salt stress (Tavares et al., 2021).

However, when the data from the NaCl solution at the lowest osmotic potential applied in the study (-0.6 MPa) were considered with the control group, there was a decrease of 51.83% and 44.08% in shoots and roots, respectively, and again, when the data from the PEG<sub>6000</sub> solution at the lowest osmotic potential applied in the study (-0.3 MPa) were considered with the control group, there was a decrease of 89.08% and 44.45% in shoots and roots, respectively. Therefore, it can be speculated that shoots were affected more adversely than roots in both NaCl and PEG<sub>6000</sub> treatments. Similarly, Perisse et al. (2002) indicated that shoot growth in *Lupinus albus* cultivar "Prima" was much more affected than root growth under different water potentials (-0.4, -0.6, and -0.8 MPa) of PEG<sub>6000</sub>. A possible explanation was offered by Munss (2002) who indicated, that the initial decrease in shoot growth was most likely due to hormonal cues produced by the roots. Roots might appear to be the most vulnerable portion of the plant since they are directly exposed to salt or drying soil, but they are surprisingly resistant. The root-to-shoot ratio is an important parameter for understanding how plants distribute biomass to adapt to stress conditions. Plants enhance root growth by making nutrients (including water) available. The root/shoot ratio increases under saline conditions (Tavares et al., 2021). In this study, it was observed that the data in the root to shoot parameter in the NaCl and PEG<sub>6000</sub> solutions at decreasing osmotic potential supported this situation (Table 1 and 2). Tavares et al., (2021) reported that increased R/S for water uptake in cowpea seedling under iso-osmotic stress (PEG<sub>6000</sub> and NaCl) conditions. Overall, increased salt and drought stress adversely affected both shoots and roots. Similarly, Li et al. (2011) reported that salt and drought (at  $\leq -0.9$  MPa NaCl and  $\leq -0.6$  MPa PEG<sub>6000</sub> osmotic potentials) stress were suppressed both shoot and root growth in pyrethrum (*Tanacetum cinerariifolium*). In addition, Yu and Rengel (1999) stated that elongation rate of shoot and root, depressed both salt and drought (osmotic potentials of -1.4 and -1.8 MPa) stress in narrow-leaved lupins (*Lupinus angustifolius* L.).

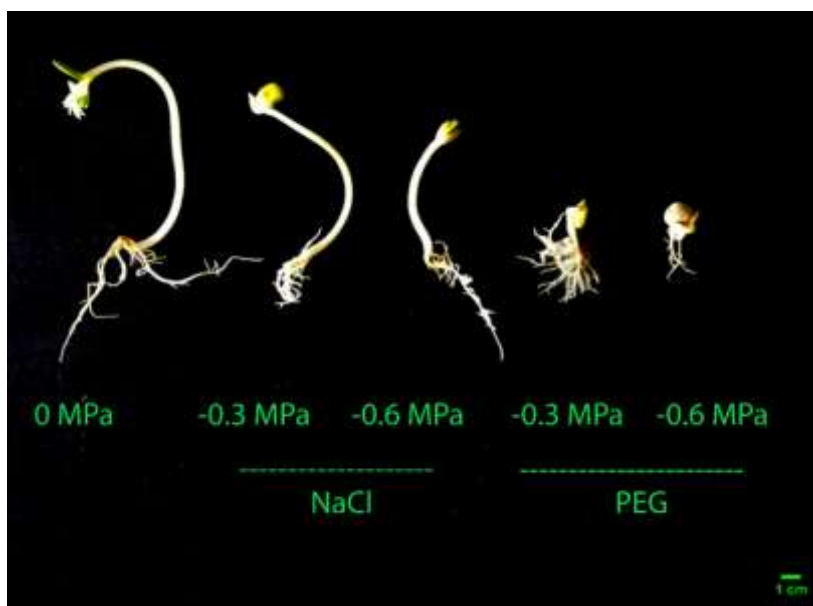


**Figure 1. The morphology of *Lupinus albus* L. seedlings after iso-osmotic potentials of NaCl and PEG<sub>6000</sub> treatments (after 21 days of germination)**

Shoot and root fresh weight, shoot and root dry weight of the *L. albus* seedlings were significantly impacted by the drought stress induced by the PEG<sub>6000</sub> solutions and by the salt stress induced by the NaCl solutions (Table 3 and 4). When compared with the control group, we observed that shoot and root fresh weight decreased in NaCl treatments at decreasing osmotic potential. This decrease was 41.17% and 38.70% for shoot and root in -0.6 MPa NaCl treatment, respectively (Table 3). However, shoot and root fresh weight decreased in PEG<sub>6000</sub> treatments at decreasing osmotic potential, compared with the control group. This decrease was 57.91% and 41.93% for shoot and root in -0.3 MPa PEG<sub>6000</sub> treatment, respectively (Table 4). On the other hand, when compared with the control group, we documented that shoot dry weight increased and root dry weight decreased in NaCl treatments at decreasing osmotic potential (Table 3). In -0.6 MPa NaCl treatment, shoot dry weight increased by 0.89% and root dry weight decreased by 22.58%. However, when compared with the control group, both shoot and root dry weight increased in PEG<sub>6000</sub> treatments at decreasing osmotic potential (Table 4). This increase was 10.76% and 12.90% for shoot and root, respectively, in -0.6 MPa PEG<sub>6000</sub> treatment. Under NaCl treatments at decreasing osmotic

**Table 1. Effects of different osmotic potential of NaCl solutions on germination percentange (GP), mean germination time (MGT), germination rate index (GRI), shoot lenght (SL), root lenght (RL), root to shoot (R/S).**

| Osmotic Potentials (MPa) | GP (%)      | MGT (day)              | GRI (%)                | SL (cm)                 | RL (cm)                | R/S (%)   |
|--------------------------|-------------|------------------------|------------------------|-------------------------|------------------------|-----------|
| 0                        | 100.00±0.00 | 4.79±0.08 <sup>b</sup> | 6.19±0.28 <sup>a</sup> | 10.90±0.41 <sup>a</sup> | 7.94±0.60 <sup>a</sup> | 0.74±0.18 |
| -0.3 NaCl                | 100.00±0.00 | 5.10±0.03 <sup>a</sup> | 4.91±0.19 <sup>b</sup> | 6.53±0.57 <sup>b</sup>  | 4.40±0.10 <sup>b</sup> | 0.68±0.06 |
| -0.6 NaCl                | 100.00±0.00 | 5.21±0.06 <sup>a</sup> | 3.86±0.17 <sup>c</sup> | 5.25±0.38 <sup>b</sup>  | 4.44±0.61 <sup>b</sup> | 0.84±0.10 |
| Means                    | 100         | 5.03                   | 4.98                   | 7.56                    | 5.59                   | 0.75      |
| <i>Summary of ANOVA</i>  |             |                        |                        |                         |                        |           |
|                          | ns          | **                     | **                     | **                      | **                     | ns        |

\*significant at  $P \leq 0.05$ , \*\* $P \leq 0.01$ , ns:non-significant. Different letters at the same column show significant differences at 0.05 level. ±: Standart Error

**Table 2. Effects of different osmotic potential of PEG<sub>6000</sub> solutions on germination percentange (GP), mean germination time (MGT), germination rate index (GRI), shoot lenght (SL), root lenght (RL), root to shoot (R/S).**

| Osmotic Potentials (MPa) | GP (%)                   | MGT (day)              | GRI (%)                | SL (cm)                 | RL (cm)                | R/S (%)                |
|--------------------------|--------------------------|------------------------|------------------------|-------------------------|------------------------|------------------------|
| 0                        | 100.00±0.00 <sup>a</sup> | 4.79±0.08 <sup>b</sup> | 6.19±0.28 <sup>a</sup> | 10.90±0.41 <sup>a</sup> | 7.94±0.60 <sup>a</sup> | 0.74±0.18 <sup>b</sup> |
| -0.3 PEG                 | 66.66±6.66 <sup>b</sup>  | 6.52±0.02 <sup>a</sup> | 1.07±0.08 <sup>b</sup> | 1.19±0.09 <sup>b</sup>  | 4.41±0.30 <sup>b</sup> | 3.71±0.17 <sup>a</sup> |
| -0.6 PEG <sup>!</sup>    | 33.33±3.33 <sup>c</sup>  | 6.68±0.17 <sup>a</sup> | 0.50±0.14 <sup>c</sup> | -                       | -                      | -                      |
| Means                    | 66.66                    | 5.99                   | 2.58                   | 4.03                    | 4.11                   | 1.48                   |
| <i>Summary of ANOVA</i>  |                          |                        |                        |                         |                        |                        |
|                          | **                       | **                     | **                     | **                      | **                     | **                     |

\*significant at  $P \leq 0.05$ , \*\* $P \leq 0.01$ . Different letters at the same column show significant differences at 0.05 level. ±: Standart Error

!: Not enough material could be obtained for parameter measurements.

**Table 3. Effects of different osmotic potential of NaCl solutions on shoot fresh weight (SFW), root fresh weight (RFW), shoot dry weight (SDW), root dry weight (RDW), shoot dry matter (SDM), root dry matter (RDM).**

| Osmotic Potentials (MPa) | SFW (mg/plant)         | RFW (mg/plant)         | SDW (mg/plant)           | RDW (mg/plant)           | SDM (%)                 | RDM (%)    |
|--------------------------|------------------------|------------------------|--------------------------|--------------------------|-------------------------|------------|
| 0                        | 2.21±0.29 <sup>a</sup> | 0.31±0.02 <sup>a</sup> | 0.223±0.006 <sup>b</sup> | 0.031±0.002 <sup>a</sup> | 10.12±0.52 <sup>b</sup> | 9.90±0.81  |
| -0.3 NaCl                | 1.39±0.04 <sup>b</sup> | 0.14±0.01 <sup>b</sup> | 0.265±0.008 <sup>a</sup> | 0.024±0.002 <sup>a</sup> | 19.09±0.52 <sup>a</sup> | 9.15±2.28  |
| -0.6 NaCl                | 1.30±0.07 <sup>b</sup> | 0.19±0.02 <sup>b</sup> | 0.225±0.002 <sup>b</sup> | 0.013±0.003 <sup>b</sup> | 17.25±0.91 <sup>a</sup> | 12.26±2.50 |
| Means                    | 1.63                   | 0.21                   | 0.237                    | 0.022                    | 15.48                   | 10.43      |
| <i>Summary of ANOVA</i>  |                        |                        |                          |                          |                         |            |
|                          | *                      | **                     | **                       | **                       | **                      | ns         |

\*significant at  $P \leq 0.05$ , \*\* $P \leq 0.01$ , ns: non-significant. Different letters at the same column show significant differences at 0.05 level. ±: Standart Error

**Table 4. Effects of different osmotic potential of PEG<sub>6000</sub> solutions on shoot fresh weight (SFW), root fresh weight (RFW), shoot dry weight (SDW), root dry weight (RDW), shoot dry matter (SDM), root dry matter (RDM).**

| Osmotic Potentials (MPa) | SFW (mg/plant)         | RFW (mg/plant)         | SDW (mg/plant)           | RDW (mg/plant)           | SDM (%)                 | RDM (%)                 |
|--------------------------|------------------------|------------------------|--------------------------|--------------------------|-------------------------|-------------------------|
| 0                        | 2.21±0.29 <sup>a</sup> | 0.31±0.02 <sup>a</sup> | 0.223±0.006 <sup>b</sup> | 0.031±0.002 <sup>a</sup> | 10.12±0.52 <sup>b</sup> | 9.90±0.81 <sup>b</sup>  |
| -0.3 PEG                 | 0.93±0.05 <sup>b</sup> | 0.18±0.02 <sup>b</sup> | 0.247±0.009 <sup>a</sup> | 0.035±0.002 <sup>a</sup> | 26.32±1.61 <sup>a</sup> | 19.13±1.16 <sup>a</sup> |
| -0.6 PEG <sup>!</sup>    | -                      | -                      | -                        | -                        | -                       | -                       |
| Means                    | 1.04                   | 0.16                   | 0.15                     | 0.022                    | 12.14                   | 9.67                    |
| <i>Summary of ANOVA</i>  |                        |                        |                          |                          |                         |                         |
|                          | **                     | **                     | **                       | **                       | **                      | **                      |

\*significant at  $P \leq 0.05$ , \*\* $P \leq 0.01$ . Different letters at the same column show significant differences at 0.05 level. ±: Standart Error

!: Not enough material could be obtained for parameter measurements.



**Table 5. Effects of different osmotic potential of NaCl solutions on shoot dry matter (R/S DM), shoot water content (SWC), root water content (RWC), seedling vigor index (SVI).**

| Osmotic Potentials (MPa) | R/S DM (%)             | SWC (%)                 | RWC (%)                  | SVI                   |
|--------------------------|------------------------|-------------------------|--------------------------|-----------------------|
| 0                        | 0.98±0.01 <sup>a</sup> | 89.87±0.52 <sup>a</sup> | 90.09±0.81 <sup>a</sup>  | 1884±160 <sup>a</sup> |
| -0.3 NaCl                | 0.48±0.03 <sup>c</sup> | 80.90±0.55 <sup>b</sup> | 90.84±2.28 <sup>a</sup>  | 1093±58 <sup>b</sup>  |
| -0.6 NaCl                | 0.70±0.05 <sup>b</sup> | 82.74±0.91 <sup>b</sup> | 87.73±2.50 <sup>ab</sup> | 969±89 <sup>b</sup>   |
| Means                    | 0.72                   | 84.50                   | 89.55                    | 1315                  |
| <i>Summary of ANOVA</i>  |                        |                         |                          |                       |
|                          | **                     | **                      | ns                       | **                    |

\*significant at  $P \leq 0.05$ , \*\* $P \leq 0.01$ . Different letters at the same column show significant differences at 0.05 level. ±: Standart Error

**Table 6. Effects of different osmotic potential of PEG<sub>6000</sub> solutions on shoot dry matter (R/S DM), shoot water content (SWC), root water content (RWC), seedling vigor index (SVI).**

| Osmotic Potentials (MPa) | R/S DM (%)             | SWC (%)                 | RWC (%)                 | SVI                   |
|--------------------------|------------------------|-------------------------|-------------------------|-----------------------|
| 0                        | 0.98±0.01 <sup>a</sup> | 89.87±0.52 <sup>a</sup> | 90.09±0.81 <sup>a</sup> | 1884±160 <sup>a</sup> |
| -0.3 PEG                 | 0.73±0.01 <sup>b</sup> | 73.67±1.66 <sup>b</sup> | 80.86±1.16 <sup>b</sup> | 378±64 <sup>b</sup>   |
| -0.6 PEG <sup>!</sup>    | -                      | -                       | -                       | -                     |
| Means                    | 0.57                   | 54.51                   | 56.98                   | 754                   |
| <i>Summary of ANOVA</i>  |                        |                         |                         |                       |
|                          | **                     | **                      | **                      | **                    |

\*significant at  $P \leq 0.05$ , \*\* $P \leq 0.01$ . Different letters at the same column show significant differences at 0.05 level. ±: Standart Error

!: Not enough material could be obtained for parameter measurements.

potential, when shoot and root dry matter were considered, there was an increase in both (except -0.3 MPa) (*Table 3*). When the lowest NaCl potential (-0.6 MPa) was compared with the control, the increase was 70.45% and 23.83% for shoot and root dry matter, respectively. However, under PEG<sub>6000</sub> treatments at decreasing osmotic potential, when shoot and root dry matter were considered, it was observed that there was an increase in both (*Table 4*). When the lowest NaCl potential (-0.3 MPa) was compared with the control, this increase was 160.07% and 93.23% for shoot and root dry matter, respectively. When compared with the control group, it was observed that the root/shoot dry matter ratio decreased due to the decreasing osmotic potential in NaCl treatments (*Table 5*). This decrease was 51.02% in -0.3 MPa NaCl treatment and 28.57% in -0.6 MPa NaCl treatment. In addition, when compared with the control group, it was observed that the root/shoot dry matter ratio decreased due to the decreasing osmotic potential in PEG<sub>6000</sub> treatments (*Table 6*). This decrease was 25.51% in -0.3 MPa NaCl treatment.

Overall, the results of the study showed that PEG<sub>6000</sub> treatments had a stronger effect on shoot and root fresh weight, shoot and root dry weight, and shoot and root dry matter than NaCl treatments. NaCl treatments at decreasing osmotic potential had more adverse effects on shoots in terms of fresh weight, and on roots in terms of dry weight and dry matter. However, PEG<sub>6000</sub> treatments at decreasing osmotic potential had more adverse effects on shoots in terms of fresh and dry weight, and on roots in terms of dry matter. Yu and Rengel (1999) stated that growth parameters such as shoot and root fresh weight restricted under both salt and drought (osmotic potentials of -1.4 and -1.8 MPa) stress in narrow-leaved lupins (*L. angustifolius* L.). Slabu et al. (2010) indicated that excess NaCl in the soil decreases vegetative development by reducing the quantity of accumulated biomass in white lupin cultivars. In addition, Perisse et al. (2002) reported that water potentials of -0.4 and -0.6 MPa PEG<sub>6000</sub> significantly reduced seedling growth of *L. albus* cultivar "Prima" developed for the central region of Argentina. Moreover, in term of dry matter, similar results were reported by Zheng et al. (2010), who showed that iso-osmotic PEG<sub>6000</sub> and NaCl treatments (-0.44 and -0.88 MPa) decreased plant dry matter accumulation rate (DMAR) of sunflower (*Helianthus annuus* L.) seedlings. Also, Beyaz et al. (2011) reported that increasing NaCl (5, 10, 20, and 30 dS/m) levels causes increase dry matter of sainfoin seedlings. Zuffo et al. (2020) emphasized that the buildup of shoot dry matter was severely hampered by salt and drought stressors in soybean genotypes, particularly in drought circumstances. Panneerselvam et al. (1998) indicated that NaCl stress decreased dry matter production of *Glycine max* seedlings. The reduction in seedling shoots dry matter due to the solution's osmotic potential is linked to a slowdown in physiological and biochemical processes, as well as challenges in hydrolysis and mobilization of reserves in the seeds caused by water deficiency (Sousa et al., 2018).

Another result of the research findings is that the NaCl solutions [(-0.3 MPa, =60 mM NaCl) and (-0.6 MPa, =121 mM NaCl)] with different osmotic potentials applied in the study have no effect on the germination percentage, which is one of the germination parameters (*Table 1*). On the other hand, the adverse effect on the vegetative growth of *L. albus* seedlings begins immediately at -0.3 MPa NaCl treatment (*Table 1, 3, and 5*). Similar to our results, Tavares et al. (2021) reported that low concentrations of NaCl ( $\leq 75$  mM) did not affect germination, but adverse affected growth. They noted that salt accumulation in plant tissues causes multiple physiological, morphological, and biochemical alterations in plant metabolism, resulting in a reduction in cell wall expansion and restriction of photosynthetic CO<sub>2</sub> uptake.

Seedling vigor index was calculated as 1884, 1093, 969 and 378 under control (0 MPa), -0.3 MPa NaCl, -0.6 MPa NaCl and -0.3 MPa PEG<sub>6000</sub> treatments, respectively (*Table 5 and 6*). Seedling vigor index decreased due to increasing salt and drought stress, this decrease was more intense in drought stress at iso-osmotic potential. Similarly, Ghiyasi et al. (2019) reported that PEG<sub>6000</sub> caused a decrease in seedling vigor index in black cumin (*Nigella sativa* L.) with its decreasing osmotic potential. Also, Borsai et al. (2018) indicated that NaCl-induced salt stress and PEG<sub>6000</sub>-induced drought stress at the same osmotic potentials causes decreasing in seedling vigor index of portulaca.

#### 4. Conclusions

In conclusion, the results of the study showed that both germination and initial seedling growth in *L. albus* were adversely affected by PEG<sub>6000</sub> and NaCl treatments at the same osmotic potential. This adverse effect was greater in PEG<sub>6000</sub> treatments than in NaCl treatments. The germination in PEG treatments was strongly compromised at an osmotic potential of -0.6 MPa, and there was no further seedling growth. In addition, it was observed that shoots were

more adversely affected than roots in salt and drought stresses caused by NaCl and PEG<sub>6000</sub> treatments. The germination and growth of *L. albus* seedlings were significantly diminished by increasing salt and drought stress, primarily due to drought stress rather than the effects of salt toxicity. Although the NaCl solutions applied in the study had adverse effects on some germination parameters such as mean germination time and germination rate index, these treatments did not have much adverse effects. Therefore, it is recommended that NaCl solutions with lower osmotic potentials be applied for *L. albus* in future studies in order to determine the dose at which germination does not occur.

#### **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

#### **Conflicts of Interest**

There is no conflict of interest.

#### **Authorship Contribution Statement**

Concept: Beyaz, R., Uslu, V. V.; Design: Beyaz, R.; Data Collection or Processing: Beyaz, R.; Statistical Analyses: Beyaz, R.; Literature Search: Beyaz, R., Uslu, V. V.; Writing, Review and Editing: Beyaz, R., Uslu, V. V.

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## The Pattern of Intra Industry Trade and Competitiveness of Agricultural Product Trade Between Indonesia and Türkiye

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### Abstract

International trade cooperation is one of the main issues faced by several countries in response to the global economic uncertainty. Indonesia is one of the countries that is active in trade cooperation both on a bilateral and regional. One of Indonesia's bilateral collaborations was the trade agreement with Türkiye in the Indonesia-Türkiye Comprehensive Economic Partnership Agreement (IT CEPA). The IT CEPA aims to improve economic relations between Indonesia and Türkiye by increasing trade. This research aims to analyze the pattern of intra-industry trade between Indonesia and Türkiye and the competitiveness of agricultural product trade. The agricultural sector has a high proportion of international trade between Türkiye and Indonesia; therefore, this study focuses on agricultural products. The method utilized is Intra-industry trade (IIT) analysis and Constant Market Share (CMS) analysis. Data on the export and import trade flows of Indonesian and Turkish commodities were obtained from the International Trade Center (ITC) database. The results showed that after the signing of the IT CEPA (2018-2022 period), exports of agricultural products increased by 45.6 percent. Indonesia has the opportunity to increase its exports to Türkiye for commodities that are declining in competitiveness. The intra-industry trade analysis showed that out of 20 two-digit HS code, only one two-digit code has strong intra-industry trade, which is HS 03 fish and crustaceans. This implied that in this HS code, both countries trade relatively in similar value. Meanwhile in other two-digit HS code, is mostly a one-way trade. The Constant Market Share (CMS) analysis revealed that the competitiveness of Indonesia's agricultural product export to Türkiye increase after the implementation of IT CEPA showing that Indonesia benefits with the implementation of this trade agreement. In the future, both countries must optimize the IT CEPA in increasing trade between two countries especially products in HS code currently only exist oneway trade.

**Keywords:** Agriculture, Constant market share analysis, Intra-industry, IT-CEPA, Trade

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## 1. Introduction

The global economic uncertainty that has occurred in recent years has had various effects on several countries. International trade cooperation is one of the main issues faced by several countries in response to these conditions. There are two types of international trade: inter and intra-industry trade (Stern, 2009). Inter-industry trade is trade between various industries, motivated by classical trade theories, called the theory of absolute advantage, the theory of comparative advantage, and the Heckscher-Ohlin theory (Sen, 2008). The current development in international trade relations has encouraged trade between countries to become increasingly complex. This can no longer be explained using the previously developed classical trading theory. Intra-industry trade is an example of a new term and theory that can explain most trading conditions currently occurring in the context of international trade. The intra-industry trade theory has been widely used in several studies. The concept of trade with the same endowment factor is called intra-industry trade (IIT), where the export value of an industry from one country is precisely balanced by imports of the same industry from another country (Kilavuz et al., 2013). The IIT will be greater if tariff and non-tariff barriers for the industry are relatively low (Greenaway et al., 1994). IIT will be larger in countries involved in various forms of economic integration because it will have an impact on reducing trade barriers, and economic integration usually occurs between neighboring countries. Indonesia is one of the countries that is active in trade cooperation both on a bilateral and regional.

One of Indonesia's bilateral collaborations is a trade agreement with Türkiye in the Indonesia-Türkiye Comprehensive Economic Partnership Agreement (IT CEPA). The IT CEPA is a forum for collaborative meetings between the two countries to discuss problems that hinder investment and trade between the two countries as well as finding solutions related to the problems found. The IT CEPA was formed so that Indonesia could increase its competitiveness in the Turkish market and catch up with other countries that had previous trade agreements with Türkiye. The IT CEPA aims to improve economic relations between Indonesia and Türkiye by increasing trade, investment, market access, services, and employment opportunities between the two countries (Dityo, 2020). In addition, the IT CEPA aims to increase economic cooperation between the two governments in various sectors. This cooperation is strategic because the aim is to actively promote the interests of domestic companies and industries, protect commodities, increase national welfare, and protect domestic industry. For Indonesia, this is an important step in securing the supply of important commodities for its industry to continue operating and maintaining its market in Türkiye. Indonesia and Türkiye are committed to increasing cooperation in politics, security, economics, culture, education, science, and technology and have set a trade volume target of 10 billion USD by 2023 (Kasim, 2023). The agreement was signed on July 7, 2017.

The research results of Darmawan et al. (2022) show that Indonesia's exports to Türkiye are less than before the IT CEPA agreement. The value of Indonesia's exports to Türkiye and Turkish exports to Indonesia decreased during 2017-2018 period (Zaimudin, 2020). This condition is interesting because IT CEPA should be able to encourage an increase in the volume of trade between the two countries, but what has happened is the opposite, where the value of trade between the two countries has decreased.

This study utilized intra-industry trade (IIT) analysis. IIT is a tool for measuring the export-import performance of a country's industry and can be used to study the interrelationship between intra-industry trade relations between Indonesia and Türkiye. In addition, a partial analysis using the IIT approach also needs to be carried out to identify the extent of the integration of potential export commodities being traded. Furthermore, Constant Market Share (CMS) analysis was used to analyze export dynamics before and after the IT CEPA agreement.

Research using the IIT method was conducted by Sunardi (2015), Adzimatur (2016) and Nainggolan (2020). Sunardi (2015) using the Intra Industry Trade (IIT) method to analyze the competitiveness and determined factors of Indonesia's superior commodity exports to member of the Organization of Islamic Cooperation (OIC). The results show that trade relations between Indonesia and the OIC member countries run in one direction. The highest degree of commodity integration occurs at the medium level of integration in petroleum coke, petroleum bitumen, and other petroleum oil residues (HS 2713) and petroleum gases (HS 2711). The Intra Industry Trade (IIT) method was also used by Nainggolan (2020) to analyze the competitiveness and factors influencing exports of selected Indonesian commodities to Developing Eight Countries (D-8). The results show that most of the intra-industry trade between Indonesia and D-8 member countries is in a one-way degree of integration; however, there are several commodities in certain destination countries that have two-way trade relations with varying degrees of

integration from weak to moderate to strong. Research has been conducted on competitiveness conditions and factors that influence trade relations between Indonesia and Türkiye (Adzimatur, 2016). The resulting IIT index shows that the trade relations between Indonesia and Türkiye run in one direction from Indonesia.

Analysis of the dynamics of export trade between Indonesia and Türkiye was carried out by Oktaviani et al. (2008) using data from 2007, when the IT CEPA agreement had not yet been implemented. This research was similar to the methods used. However, Oktaviani et al. (2008) examined Indonesian exports to the Middle East, including Türkiye, Tunisia, and Morocco. This study focused on Indonesia's trade with Türkiye. This research also has similarities with Adzimatur (2016) regarding the use of the IIT method and the export destination country, Türkiye. The difference is that the research analyzes Indonesia's leading export commodities, whereas this research emphasizes agricultural products.

One of the methods to analyze the effect of trade agreements is using constant market share (CMS) analysis. Shah et al. (2020) analyze whether Pakistan and China trade agreement promote export. The result indicates that Pakistan export growth was contributed by the market demand effect and competitiveness effect showing that the free trade agreement benefits both countries. Meanwhile Kamal et al. (2021) utilized CMS analysis and gravity model to analyze the trade competitiveness and trade potential of Pakistan and ASEAN countries in the Chinese market. The results reveal that Pakistan along with Brunei, Cambodia, Laos, Myanmar, Philippines, and Thailand has great trade potential in the Chinese market. In addition, Pakistan's export performance in China's market relies on the market distribution effect.

Trade analysis will be carried out in the agricultural sector, since it is one of the sectors that has a high proportion of international trade between Türkiye and Indonesia. Growth in the trade value of this sector is important for increasing the trade value of the two countries (Sumiahadi et al., 2021). Therefore, this study aims to analyze the intra-industry trade patterns of Indonesian agricultural products based on the degree of integration with Türkiye and analyze the dynamics of trade between Indonesia and Türkiye before and after the IT CEPA agreement. It is hoped that the results of this research can contribute to evaluating the IT CEPA agreement in order to improve it.

## 2. Materials and Methods

This study uses secondary data on export and import trade flows of Indonesian and Turkish commodities obtained from the International Trade Center (ITC) database. Trade data use a two-digit harmonized system code (HS code). Agricultural products in this research are defined as products originating from plants and animals in both raw and processed forms, with the HS codes of 01 to 24, plus HS 40 and HS 44.

The Intra Industry Trade (IIT) method was utilized to analyze the level of trade integration between Indonesia and Türkiye. Intra-industry trading patterns are determined using the Grubel-Lloyd Index (GLI) method. The Grubel-Lloyd Index (GLI) method can be formulated as follows (Grubel and Lloyd, 1971)

$$GLI_i = 1 - \frac{\sum(X_i - M_i)}{\sum(X_i + M_i)} \quad (\text{Eq. 1})$$

$GLI_i$ : Intra industry trade of product i

$X_i$  : Export value of product i

$M_i$  : Import value of product i

$i$  : Types of products.

$GLI_i$  measures average intra-industry trade as a ratio of the export plus import trade which is also equal to the sum of the intra-industry trade for the industries of the i industries (Grubel and Lloyd, 1971). The index value  $GLI_i$  has a value range between 0 to 1. If the index value  $GLI_i = 0$ , it means that a country only trades in exports or imports of a commodity in the same industry (there is no intra-industry trade pattern). Meanwhile, if the index value  $GLI_i = 1$ , it means that a country exports and imports a commodity in the same industry and in the same quantity (there is a maximum intra-industry trade pattern). The results of the Intra Industry Trade (IIT) analysis will be used as an indicator to determine the level of integration of agricultural products. Table 1 shows the IIT value classification.

**Table 1. IIT value classification**

| IIT Value           | Level of Integration            |
|---------------------|---------------------------------|
| ITT= 0.00           | No integration (oneway trading) |
| 0.00 < IIT < 24.99  | Weak integration                |
| 25.00 < IIT < 49.99 | Medium integration              |
| 50.00 < IIT < 74.99 | Moderate strong integration     |
| 75.00< IIT<100.00   | Strong integration              |

The Constant Market Share (CMS) analysis was first applied by Tyszynski (1951). The original paper decomposed the export growth into four components and mostly utilized for the entire export products (Richardson, 1971): market size effect, market composition effect, commodity composition effect and competitive effect. In this paper, since only one market analyzed, which Turkey, therefore the export growth has only three components, namely: market size, commodity composition, and competition effects. The market-size effect shows that a country's export growth is caused by an increase in destination market imports. Market size effects result from changes in global demand. The commodity composition effect shows whether a country has concentrated on commodities with rapidly growing markets. Furthermore, the competitiveness effect is the remainder of the CMS and is not explained by the other three effects. This research will compare the time period before IT CEPA was 2012-2016 period and after IT CEPA was 2018-2022 period. The formula used in the CMS analysis is based on Shah et al. (2020):

$$\Delta X = \sum_{i=1}^n rX_i + (\sum_{i=1}^n r_iX_i - \sum_{i=1}^n rX_i) + (\sum_{i=1}^n \sum_{j=1}^n r_{ij}X_{ij} - \sum_{i=1}^n r_iX_i) \quad (\text{Eq. 2})$$

$\Delta X$  = changes in the value of Indonesian agricultural exports to Türkiye from period 1 to period 2

$r$  = changes of Turkish agricultural imports from period 1 to period 2 (%)

$r_i$  = changes in Indonesian agricultural exports to Türkiye in commodity  $i$  from the period 1 to period 2 (%)

$r_{ij}$  = changes in Turkish agricultural imports of commodity  $i$  from period 1 to period 2 (%)

$X_i$  = the value of exports of Indonesian agricultural products to the world in commodity  $i$  in period 1 to period 2

$X_{ij}$  = value of exports of Indonesian agricultural products to Türkiye for commodity  $i$  in period 1 to period 2

$\sum_{i=1}^n rX_i$  = market size effect

$(\sum_{i=1}^n r_iX_i - \sum_{i=1}^n rX_i)$  = commodity composition effects

$(\sum_{i=1}^n \sum_{j=1}^n r_{ij}X_{ij} - \sum_{i=1}^n r_iX_i)$  = competitiveness effect

### 3. Results and Discussion

#### 3.1. Trade Flows and Linkages between Indonesia and Türkiye

Before the IT CEPA agreement, Indonesia-Türkiye trade was more in favor of Indonesia, as indicated by Indonesia's trade surplus. In the 2010-2016 period, Indonesia's largest trade surplus occurred in 2013, with a surplus of almost 1.3 billion US\$ (*Figure 1*). After the IT CEPA agreement in 2017, Indonesia's trade surplus increased and reached its highest level in 2022, with a surplus of US\$ 1.7 billion (*Figure 1*).

The increase in exports occurred during Covid-19 and after which Indonesia's exports to Türkiye increased significantly by 2021, with an increase of 53 percent. The highest increase in Turkish exports to Indonesia occurred in 2021, with an increase of 46 percent. Indonesia's largest export product to Türkiye is derivative palm oil products (HS 151190), with an export value of US\$ 512 million or reaching 24.7 percent of the total value of Indonesia's exports to Türkiye in 2022. Türkiye's largest exports to Indonesia were part of gas turbines (HS 841199) amounting to US\$ 30.9 million or 8.5 percent of the total value of Türkiye's exports to Indonesia in 2022. For agricultural products, Türkiye's largest export to Indonesia was tobacco (HS 240110) amounting to US\$ 29.6 million or 8 percent of the total value of Türkiye's exports to Indonesia in the same period. This shows that Indonesia's exports to Türkiye are dominated by several main products, whereas Türkiye's exports to Indonesia are relatively the same in value. This study inferred that agricultural products are traded between Indonesia and

Türkiye. Twenty agricultural products in the two-digit HS codes are traded. The link between trade in Indonesian and Turkish agricultural products is shown by the intra-industry trade (ITT) values in *Table 2*.

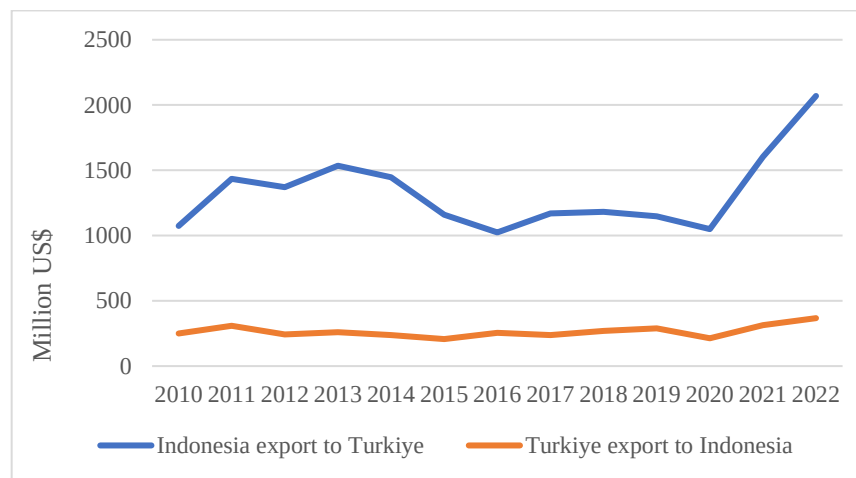


**Figure 1. Value of Indonesian Exports to Türkiye and Türkiye Exports to Indonesia (2010-2022)**

Source: TradeMap (2023),

Fish and crustaceans, mollusks, and other aquatic invertebrates (HS 03) have the highest intra-industry trade (IIT) value, with a value of 86.75 (strong integration). This is because Indonesia's exports to Türkiye amounted to 874 thousand US\$ and imports from Türkiye amounted to US\$ 1.1 million. Indonesia's largest export of fish and crustaceans, molluscs and other aquatic invertebrates (HS 03) in 2022 is tuna fillet (HS 030487) with an export value of US\$ 240 thousand while Türkiye's exports to Indonesia in this HS is frozen trout (HS 030314) with an export value in 2022 of US\$ 970 thousand. For Indonesia, a maritime country, fishery products are one of the mainstays of exports. Meanwhile, for Türkiye, the fishing industry also occupies an important position in economic and social growth (Eyüboğlu and Akmermer, 2023; Kale, 2020; Karataş, 2017). Seafood, especially fish is an important source of protein in many diets around the world (Azabagaoglu et al., 2016)

The cocoa and cocoa preparations (HS 18) showed moderately strong integration. The products exported by Indonesia to Türkiye are cocoa butter, fat, and oil (HS 180400); cocoa powder (HS 180500 and HS 180610); and cocoa beans (HS 180100), with the highest value being cocoa butter, fat, and oil (HS 180400). Exports in 2022 amounted to 6.2 million US\$. The products imported from Türkiye are chocolate (HS 180690, HS 180620, and HS 180632), with the largest export value in 2022 being chocolate (180690) amounting to US\$ 2.7 million. This shows that the products imported from Türkiye are finished products that are ready for consumption, whereas Indonesia exports raw and semi-finished products.

Other products with moderate integration are miscellaneous edible preparations (HS 21). Products exported by Indonesia are preparations for sauces and prepared sauces, mixed condiments and seasonings (HS 210390), food preparations consisting of finely homogenized mixtures of two or more basic ingredients (HS 210420), food preparations (HS 210690), extracts, essences, and concentrates of coffee (HS 210111). Indonesia's largest exports to Türkiye are preparations for sauces and prepared sauces, mixed condiments, and seasonings (HS 210390), with an export value of US\$ 12 million in 2022. Turkish products exported to Indonesia include ice cream and other edible ice, whether or not they contain cocoa (HS 210500), inactive yeasts, other dead single-cell microorganisms (HS 210220), food preparations (HS 210690), protein concentrates and textured protein substances (HS 210610), prepared baking powder (HS 210230), soups and broths and preparations (HS 21040), preparations for sauces and prepared sauces, and mixed condiments and seasonings (HS 210390). Türkiye's export to Indonesia for HS 21 is yeast (HS210210) with a value in 2022 of US\$ 2.5 million.

Türkiye is one of the most important producers and exporters countries of dried fruit (Ertemli and Demirbas, 2015). Edible fruit and nuts; peel of citrus fruit or melons (HS 08) are the products imported by Indonesia from Türkiye includes fresh or dried hazelnuts (HS 080222), dried grapes (HS 080620), fresh tamarind, cashew, jackfruit, lychee, sapodilla plum, passion fruit, starfruit (HS 081090), fresh cherries (HS 080929), dried apricots (HS 081310), fresh or dried figs (HS 080420), fresh apricots (HS 080910), fresh or dried dates (HS 080410), fresh

or dried pistachios, shelled (HS 080252), fresh plums and sloes (HS 080940). Meanwhile, the products exported by Indonesia are desiccated coconuts (HS 080111) and fresh coconuts in the inner shell "endocarp" (HS 080112). This shows that the types of fruit and nuts imported from Türkiye are subtropical products that are difficult to produce in Indonesia. Coconut is the only product in this group that Indonesia exports to Türkiye in dry or fresh form.

**Table 2. Trade Flow and Intra Industry Trade (IIT) between Indonesia and Türkiye in 2022**  
(in thousand US\$)

| HS code | Product                                                                                        | Export  | Import | IIT   | Level of Integration |
|---------|------------------------------------------------------------------------------------------------|---------|--------|-------|----------------------|
| 03      | Fish and crustaceans, molluscs and other aquatic invertebrates                                 | 874     | 1.141  | 86.75 | Strong               |
| 05      | Products of animal origin, not elsewhere specified or included                                 | 602     | 0      | 0     | None                 |
| 06      | Live trees and other plants; bulbs, roots and the like; cut flowers and ornamental foliage     | 16      | 0      | 0     | None                 |
| 08      | Edible fruit and nuts; peel of citrus fruit or melons                                          | 5.869   | 1.472  | 40.10 | Moderate strong      |
| 09      | Coffee, tea, and spices                                                                        | 4.593   | 376    | 15.13 | Weak                 |
| 11      | Products of the milling industry; malt; starches; inulin; wheat gluten                         | 7       | 3.047  | 0.46  | Weak                 |
| 12      | Oil seeds and oleaginous fruits; miscellaneous grains, seeds and fruit                         | 0       | 128    | 0     | None                 |
| 13      | Lac; gums, resins and other vegetable saps and extracts.                                       | 596     | 3      | 1.00  | Weak                 |
| 14      | Vegetable plaiting materials; vegetable products not elsewhere specified or included           | 84      | 0      | 0     | None                 |
| 15      | Animal, vegetable or microbial fats and oils and their cleavage products; prepared edible fats | 602.650 | 2.438  | 0.80  | Weak                 |
| 17      | Sugars and sugar confectionery                                                                 | 110     | 7,531  | 2.88  | Weak                 |
| 18      | Cocoa and cocoa preparations                                                                   | 9.334   | 3.294  | 52.17 | Moderate strong      |
| 19      | Preparations of cereals, flour, starch or milk; pastrycooks' products                          | 57      | 1.016  | 10.62 | Weak                 |
| 20      | Preparations of vegetables, fruit, nuts or other parts of plants                               | 38      | 2.131  | 3.50  | Weak                 |
| 21      | Miscellaneous edible preparations                                                              | 14.924  | 5.223  | 51.85 | Moderate strong      |
| 22      | Beverages, spirits and vinegar                                                                 | 0       | 100    | 0     | None                 |
| 23      | Residues and waste from the food industries; prepared animal fodder                            | 7.386   | 62     | 1.66  | Weak                 |
| 24      | Tobacco and manufactured tobacco substitutes                                                   | 1.449   | 30.485 | 9.07  | Weak                 |
| 40      | Rubber and articles thereof                                                                    | 137.694 | 3.419  | 4.85  | Weak                 |
| 44      | Wood and articles of wood                                                                      | 15.507  | 165    | 2.11  | Weak                 |

Tobacco and manufactured tobacco substitutes (HS 24) are the products that Türkiye imported the most from Indonesia; however, Indonesia's exports for this product are small, so the IIT value shows weak integration. Products exported by Indonesia are tobacco, "homogenized" (HS 240391), tobacco, partially or completely stemmed or peeled (HS 240120), cigarettes containing tobacco (HS 240220), tobacco, unstemmed or unpeeled (HS 240110), tobacco refuse (HS 240130), cigars and cigars containing tobacco (HS 240210). The products exported by Türkiye are tobacco, unstemmed or unstripped (HS 240110), tobacco, partly or wholly stemmed or stripped, otherwise unmanufactured (HS 240120), tobacco refuse (HS 240130), water pipe tobacco (HS 240311),

cigarettes containing tobacco (HS 240220), chewing tobacco, snuff, and other manufactured tobacco (HS 240399), smoking tobacco, and tobacco substitutes (HS 240319).

Animal, vegetable, and microbial fats and oils and their cleavage products (HS 15) are Indonesia's largest agricultural products exported to Türkiye. The products exported by Indonesia are palm oil and its fractions, refined (HS 151190), edible mixtures or preparations from animal or vegetable fats or oils (HS 151790), palm kernel and babassu oil and its fractions (HS 151329), vegetable fats and oils and their fractions (HS 151620), coconut oil and its fractions (HS 151319), and crude coconut oil (HS 151311). By 2022, Indonesia's largest export to Türkiye was palm oil. Türkiye requires this oil as a raw material for biodiesel production (Lutfi, 2021). This is in accordance with the research of Oktaviani et al. (2008) where in 2007, animal fats and vegetables were also the commodities that contributed the most to Türkiye's exports. Crude palm oil (CPO) imports are an alternative to Türkiye to meet its vegetable oil needs. This causes the price of palm oil to decrease. Türkiye also exports sunflower seed or safflower oil and its fractions (HS 151219), edible mixtures or preparations of animal or vegetable fats or oils and edible fractions (HS 151790), virgin olive oil (HS 150930), extra virgin olive oil (HS 150920), margarine (HS 151710), and other oils and their fractions (HS 151090) to Indonesia.

### 3.2. The Competitiveness of Indonesian Agricultural Product Export to Türkiye

Trade in agricultural products between Indonesia and Türkiye was divided into two periods. The 2012-2016 period shows conditions before the IT CEPA agreement and 2018-2022 shows the 2018-2022 period. *Figure 2* shows the dynamics of trade in agricultural products between the two countries before IT-CEPA and *Figure 3* shows trade in agricultural product after IT-CEPA.

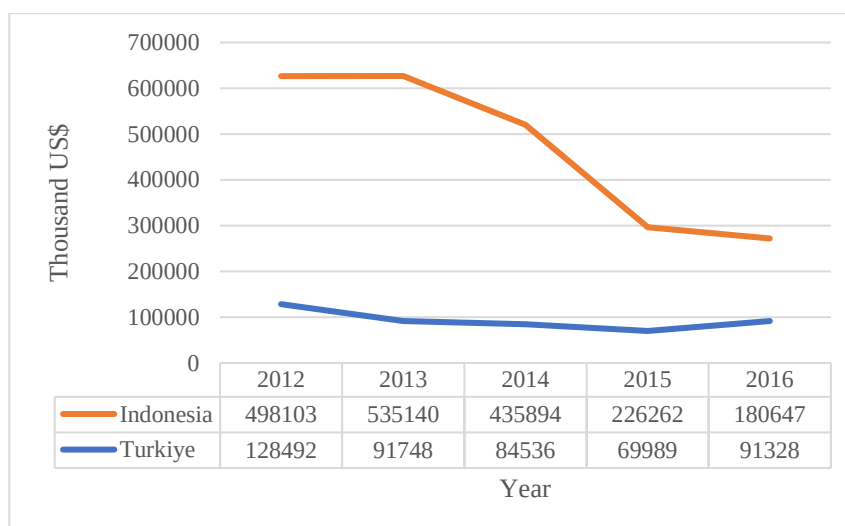


**Figure 2. Value of Indonesian Exports Agricultural Product to Türkiye and Türkiye Exports Agricultural Product to Indonesia Before IT-CEPA**

Source: TradeMap (2023)

The dynamics of export growth are analyzed using Constant Market Share (CMS). *Table 3* shows that in the 2012-2016 period there was a decline in exports from Indonesia to Türkiye. This decline in exports occurred because of commodity composition, competitiveness, and market size. The biggest contributor to this decline was that Indonesian exports experienced a decline in competitiveness compared to exports from other countries. Approximately 87.2 percent of the decline in Indonesian exports was caused by a decline in competitiveness, followed by a commodity composition of 7.6%, and a market size of 5.2 percent.

The decrease in the market size effect shows that in this period, Türkiye's domestic demand for imported commodities from all countries weakened. Meanwhile, the commodity composition effect, which is negative, indicates that Indonesia's export growth to Türkiye is lower than the growth in Türkiye's imports of these products from countries other than Indonesia.

Standard growth parameters show that the growth in exports of Indonesian agricultural products to Türkiye decreased by 13.1 percent. Indonesia's standard export growth to Türkiye is lower than exports to the world; thus,



Indonesia's export performance has decreased. Three commodities experienced the greatest decline in competitiveness: fat and oil products, both animal and vegetable (HS 15), especially palm oil derivatives, rubber (HS 40) and malt milling products, wheat, gluten, inulin, and starch (HS 11). Meanwhile, three commodities experienced the largest increase, namely wood (HS 44), residues and waste from the food industry (HS 23), and miscellaneous edible preparations (HS 21).

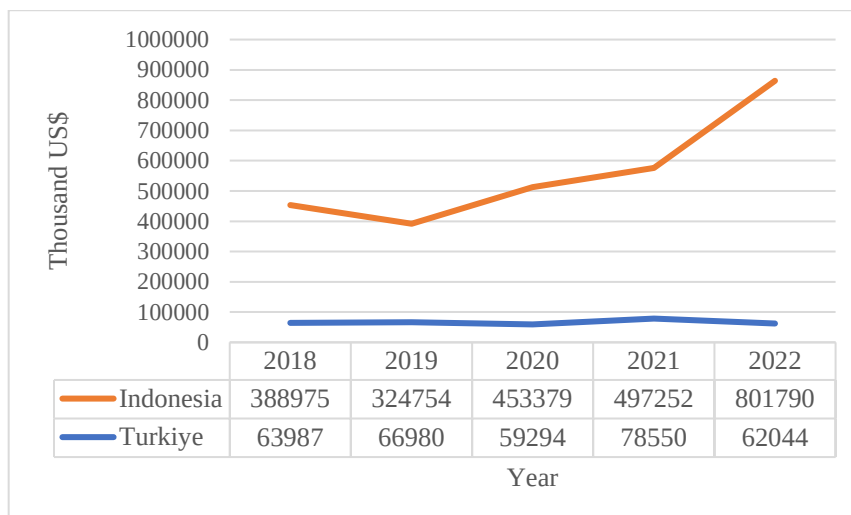


**Figure 3. Value of Indonesian Exports Agricultural Product to Türkiye and Türkiye Exports Agricultural Product to Indonesia After IT-CEPA**

Source: TradeMap (2023)

**Table 3. Components of Growth in Exports of Indonesian Agricultural Products to Türkiye**

| No | Components                   | Before IT CEPA | After IT CEPA |
|----|------------------------------|----------------|---------------|
| 1  | Export growth                | -387.093       | 461.552       |
| 2  | Market size                  | -20.113        | 191.595       |
| 3  | Commodity composition effect | -29.607        | 47.756        |
| 4  | Competitiveness effect       | -337.372       | 222.202       |

After the signing of the IT-CEPA (2018-2022 period), exports of agricultural products increased by 45.6 percent. This occurred because there was an increase in all components, namely market size, commodity composition, and the influence of competitiveness. The effect of product composition shows that Indonesia's concentration on agricultural product exports is growing rapidly. The effect of this product composition is positive, which means that Indonesia's export products to Türkiye have higher product import growth compared to imports from other countries in Türkiye. Indonesia's main export to Türkiye, namely derivative palm oil (HS 151190), experienced an increase in value of 246.79 percent in the 2018-2022 period, while in terms of quantity it increased by 106.52 percent in the same period. This shows that, apart from being influenced by the quantity of exports, this increase was also influenced by a significant increase in prices. Türkiye's demand for derivative palm oil is predicted to increase (Koc et al., 2005). The realization of CEPA for Indonesia has an important meaning in external consultations or the involvement of private actors in the context of Indonesia's economic diplomacy in the palm oil sector (Lutfi, 2021).

From the results of the CMSA analysis, three commodities experienced the greatest increase in competitiveness after the IT-CEPA agreement: fat and oil products, both animal and vegetable (HS 15), especially palm oil derivatives, miscellaneous edible preparations (HS 21), and coffee and spice products, tea, and mates (HS 09). Meanwhile, the three commodities that experienced the greatest decline in competitiveness were rubber (HS 40); malt milling products, wheat, gluten, inulin, and starch (HS 11); and processed products from vegetables, fruits, and other types of plants (HS 20).

The results of the IIT and CMSA analyses show that Indonesian export commodities with increased competitiveness generally have low IIT, except for miscellaneous edible preparations (HS 21). This low IIT value is because trade is dominated only by Indonesia. However, Indonesia's commodities that experience decreasing competitiveness also have low IIT values and are dominated by Indonesian exports only. This shows that there is still an opportunity for Indonesia to increase its exports of Türkiye for these three commodities, which are experiencing a decline in competitiveness.

#### **4. Conclusions**

The exports of Indonesia's agricultural products increased by 45.6 percent after the signing of the IT CEPA (2018-2022 period). The commodities that increased competitiveness were fat and oil products, both animal and vegetable (HS 15), especially palm oil derivatives; other processed products that can be consumed (HS 21); and coffee, spices, tea, and maté products (HS 21). HS 09). Indonesian export commodities with increased competitiveness generally have low IIT, except for other processed products that can be consumed (HS 21). Meanwhile, the three commodities that experienced the greatest decline in competitiveness were rubber (HS 40); malt milling products, wheat, gluten, inulin, and starch (HS 11); and processed products from vegetables, fruits, and other types of plants (HS 20). This indicates that Indonesia has benefited with the implementation of this trade agreement.

The intra-industry trade analysis showed that out of 20 two-digit HS code, only one two-digit code has strong intra-industry trade, which is HS 03 fish and crustaceans. The low IIT value is because trade is dominated by Indonesia. On the other hand, Indonesian commodities which experience a decline in competitiveness also have low IIT values and are dominated by Indonesian exports only. This shows that Indonesia still has an opportunity to increase its exports to Türkiye for these three commodities, which are experiencing a decline in competitiveness.

#### **Acknowledgment**

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#### **Ethical Statement**

This study was prepared under the permission numbered 80/R-UMJ/VII/2023 dated 10/07/23, from the Ethics Committee of Universitas Muhammadiyah Jakarta.

#### **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

#### **Authorship Contribution Statement**

Concept: Naully, D., Rifin, A.; Design: Naully, D., Rifin, A.; Data Collection or Processing: Rahmadona, L., Khoirotun Novila, N.; Statistical Analyses: Naully, D.; Literature Search: Naully, D.; Writing, Review and Editing: Naully, D.

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**Production of Functional Kombucha Enhanced with Mormix, Mulberry Powder and Different Concentrations of Whey\***

Farklı Konsantrasyonlarda Peynir Altı Suyu, Mormix ve Dut Tozu ile Zenginleştirilen Fonksiyonel Kombucha Üretimi

Esra BEBEK<sup>1</sup>, Filiz YANGILAR<sup>2\*</sup>

**Abstract**

In this study, the fortified fermented beverages with Kombucha culture (SCOBY) and different concentrations of whey (25%, 50%, 75%) by using mulberry powder to give natural sweetness with mormix rich in bioactive components during fermentation (1<sup>st</sup>, 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup>, 11<sup>th</sup> and 13<sup>th</sup> days) microbiological, physicochemical and sensory properties were planned. This effort was to develop an innovative, functional, and immune-boosting product by combining Mormix, which is rich in bioactive compounds, and nutritionally valuable whey in the production of Kombucha tea. The lowest acetic acid bacteria count (6.87 log<sub>10</sub> cfu mL<sup>-1</sup>) was found in the control sample, and the highest (8.07 log<sub>10</sub> cfu mL<sup>-1</sup>) was found in the sample produced with green tea+75% whey+mormix+mulberry powder (KMP<sub>3</sub>). *Lactobacillus* spp. and *Lactococcus* spp. counts were determined to be the highest in the KMP<sub>3</sub> sample. The effect of the samples on the mold counts developed in Kombucha beverages was statistically significant ( $p<0.01$ ). Using green tea and different raw materials for Kombucha fermentation caused changes in dry matter, titration acidity, and pH values. The viscosity results were very significant during fermentation and adding different concentrations of whey and mormix+mulberry powder ( $p<0.01$ ). It was determined that the  $L^*$ ,  $a^*$ ,  $b^*$ ,  $C$ ,  $\alpha^\circ$ , and  $\Delta E^*$  color parameters of Kombucha enriched with whey and mormix+mulberry powder changed during fermentation. In fermented beverage samples made with Kombucha culture, an increase was observed in total phenolic content (981.33-1515.30 mg GAE g<sup>-1</sup>) and antioxidant capacity (DPPH 59.03-94.29%) during fermentation depending on the raw materials added. The sensory analysis showed that the most preferred sample was green tea+25% whey+mormix+mulberry powder (KMP<sub>1</sub>). Increasing the fermentation time caused an increase in acidity, and on the 13<sup>th</sup> day, KMP<sub>2</sub> and KMP<sub>3</sub> were the samples with the lowest taste scores. It has been obtained from the thesis findings that Kombucha can be evaluated as a new fermented beverage because raw materials such as whey and mormix used in its production provide strong antioxidant properties.

**Keywords:** Kombucha, Functional beverage, Mormix, Mulberry powder, Whey

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Atf: Bebek, E., Yangılar, F. (2025). Farklı konsantrasyonlarda peynir altı suyu, mormix ve dut tozu ile zenginleştirilen fonksiyonel kombucha üretimi. *Tekirdağ Ziraat Fakültesi Dergisi*, 22(2): 396-410.

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## Öz

Bu çalışmada Kombu çayı kültürü (SCOBY) ile peyniraltı suyunun (PAS) farklı konsantrasyonları (%25, %50, %75) ve biyoaktif bileşenlerce zengin olan mormiks ile doğal tatlılık vermesi amacıyla dut tozu kullanılarak zenginleştirilen fermente içeceklerin fermentasyon süresince (1., 5., 7., 9., 11. ve 13. günler) mikrobiyolojik, fiziko-kimyasal ve duyusal özelliklerinin incelenmesi planlanmıştır. Buradaki amaç biyoaktif bileşik içeriği çok fazla olan mormiks ile besinsel yönden çok değerli olan peynir altı suyunun Kombu çayı üretiminde kullanılarak yenilikçi, fonksiyonel ve bağışıklık sistemini güçlendirici bir ürün geliştirilmesine imkân sunmaktır. Mikrobiyolojik analizlerin sonucunda, en düşük asetik asit bakteri sayısı ( $6,87 \log_{10}$  kob  $\text{mL}^{-1}$ ) kontrol örneğinde, en yüksek ( $8,07 \log_{10}$  kob  $\text{mL}^{-1}$ ) ise yeşil çay+%75 PAS+mormiks+dut tozu (KMP<sub>3</sub>) ile üretilen örnekte bulunmuştur. *Lactobacillus* spp. ve *Lactococcus* spp. sayıları en yüksek bulunan örnek KMP<sub>3</sub> örneği olmuştur. Kombu çayı içeceklerinde gelişen maya sayıları üzerinde örneklerin etkisi çok önemli tespit edilmiştir ( $p<0,01$ ). Kombu çayı fermentasyonu için yeşil çay ile farklı hammaddelerin kullanımı kurumadde, titrasyon asitliği ve pH değerlerinde değişikliklere neden olmuştur. Farklı konsantrasyonlarda PAS ve mormiks+dut tozu ile katkılandırmanın ve fermentasyonun viskozite sonuçları üzerindeki etkisi çok önemli ( $p<0,01$ ) bulunmuştur. PAS ve mormiks+dut tozu ile zenginleştirilen Kombu çaylarının  $L^*$ ,  $a^*$ ,  $b^*$ ,  $C$ ,  $\alpha^\circ$  ve  $\Delta E^*$  renk parametrelerinin fermentasyon süresince değiştiği belirlenmiştir. Kombu çayı kültürü ile yapılan fermente içecek örneklerinde ilave edilen hammaddelere bağlı olarak toplam fenolik madde ( $9813,33\text{-}1515,3 \text{ mg GAE g}^{-1}$ ) ve antioksidan kapasitelerinde (DPPH %59,03-94,29) fermentasyon boyunca artış saptanmıştır. Duyusal analiz sonucuna göre en beğenilen ürün yeşil çay+%25 PAS+mormiks+dut tozu (KMP<sub>1</sub>) ile hazırlanan fermente içecek olmuştur. Fermentasyon gününün artması asitlik miktarında artışa neden olmuş ve 13. gününde KMP<sub>2</sub> ve KMP<sub>3</sub> tat puanını en düşük alan örnekler olmuştur. Üretiminde kullanılan PAS ve mormiks gibi hammaddeler kuvvetli antioksidan özellik kazandırdığı için yeni bir fermente içecek olarak Kombu çayının değerlendirilebileceği sonucu çalışma bulgularından elde edilmiştir.

**Anahtar Kelimeler:** Kombucha, Fonksiyonel içecek, Mormiks, Dut tozu, Peynir altı suyu

## 1. Introduction

A healthy diet requires an adequate intake of nutrients. Diversity is equally crucial to nutritional intake (Yılmaz and Çolakoğlu, 2024). Fermented foods are reliable products, with taste and aroma serving as additional factors influencing their consumption (Dağlıoğlu et al., 2002; Şensoy and Tarakçı, 2023). Kombucha beverages are functional foods, and their popularity is due to their multiple functional properties, such as anti-inflammatory potential and antioxidant activity (Villarreal-Soto et al., 2018). Among the beneficial components of Kombucha are polyphenols, amino acids, vitamins, antibiotics, and various micronutrients produced during fermentation (Jayabalan et al., 2007). The various effects of Kombucha on human health, such as accelerating digestion, preventing microbial infections, protecting against stress and cancer, and providing prophylactic and therapeutic benefits for hemorrhoids, have been determined. It has also been reported that it is effective at lowering cholesterol levels, removing toxins from the body, and cleansing blood (Dufresne and Farnworth, 2000; Malbaša et al., 2011; Jayabalan et al., 2014; Amarasinghe et al., 2018). The incidence of metabolic disorders such as diabetes, cardiovascular diseases, and obesity is associated with increased sugar consumption (Özdemir et al., 2015; Arslaner and Salık, 2017). As consumer demands for low-calorie foods have increased, products produced with alternative sweeteners have become more popular in recent years. One of the fruits that is appetizing and low in calories is mulberry (Wang et al., 2013). It has been reported that this fruit has pharmacological effects through its anti-inflammatory, anticholesterol, antidiabetic, antioxidant, and antiobesity properties (İnanç et al., 2020; Kang et al., 2006; Kim and Park, 2006; Ye et al., 2002; Yu et al., 2021; Zhang and Shi, 2010; Özbacı et al., 2023). However, whey proteins have high biological value and contain many essential amino acids (lysine, tryptophan, isoleucine, threonine, etc.). Whey proteins have a higher protein efficiency ratio (PER) than casein (Walzem et al., 2002). Moreover, it contains higher concentrations of essential and sulphur-containing amino acids than egg, milk, casein, red meat, soy, corn, and wheat proteins. (Smithers, 2008; Kumar et al., 2018). In addition, whey proteins are also known to be effective as antioxidants, antibacterial agents, antihypertensive agents, antitumor agents, antiviral agents, and hypolipidemics (Rezende et al., 2014; Bilal and Altiner, 2017; Yüksel et al., 2019).

The presence of mormix, a product extremely rich in bioactive compounds, is extremely important for improving the immune system. It is the concentrated color substance of the color components of purple-colored fruits and vegetables and provides the purple color resulting from the purple pigment content in these fruits (Baylan and Badem, 2023). The mormix makes important contributions, especially to blood vessels, by preventing blockage in the heart, brain, and leg vessels. Regulating the body's glycemic index protects against many chronic diseases, especially diabetes. Mormix, which is required to be produced and consumed in Japan, has become increasingly popular due to its effects on human health, and their production has begun in many countries (Cömert and Gün, 2020).

When preparing innovative foods, they must be produced by considering the acceptance conditions of consumers. In this context, it has been shown that the nutritional content of Kombucha, an innovative food, can be further improved by the use of whey, which is used as waste in the dairy by product industry, and mormix a good source of antioxidants. Upon reviewing current literature, no nutritionally rich Kombucha made with whey, mormix, and mulberry powder was found. Given the prevalence of chronic diseases in today's world, creating a health-promoting nutraceutical product has made this study particularly significant compared to existing research.

## 2. Materials and Methods

### 2.1. Materials

Green tea leaves (*Camellia sinensis*), starter culture (SCOBY) [(CENTRAGEN Laboratory Products Informatics and Consultancy Company)], dried mulberry, sucrose, and mormix (Sankara Food) were obtained from the market.

### 2.2. Kombucha production

The ratios determined after preliminary trials, taking into account previous studies, were used to formulate the Kombucha samples (Table 1).



Table 1. Kombucha sample formulations

| Groups           | Pure water (mL) | Whey (mL) | Mulberry powder (g/3L) | Mormix (g/3L) |
|------------------|-----------------|-----------|------------------------|---------------|
| K                | 3000            | 0         | 0                      | 0             |
| KMP <sub>1</sub> | 2250            | 750       | 180                    | 90            |
| KMP <sub>2</sub> | 1500            | 1500      | 180                    | 90            |
| KMP <sub>3</sub> | 750             | 2250      | 180                    | 90            |

\*K: Control (only green tea); KMP<sub>1</sub>: Green tea+25% Whey+mormix+mulberry powder; KMP<sub>2</sub>: Green tea+50% whey+mormix+mulberry powder and KMP<sub>3</sub>: Green tea+75% whey+mormix+mulberry powder.

Fermented beverages were produced by brewing at 90°C for 10 min according to the methods of Jayabalan et al. (2007). The filtered mixture was cooled to 28–30°C, after which mulberry powder and mormix were added. Then, 10% SCOBY Kombucha culture was added. The brewed teas were left to ferment at 25±2°C. During fermentation, analyses were performed on the 1<sup>st</sup>, 3<sup>rd</sup>, 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup>, 11<sup>th</sup>, and 13<sup>th</sup> days. A flow chart of the production of Kombucha fruits produced with different concentrations of whey or mormix+mulberry powder is shown in Figure 1.

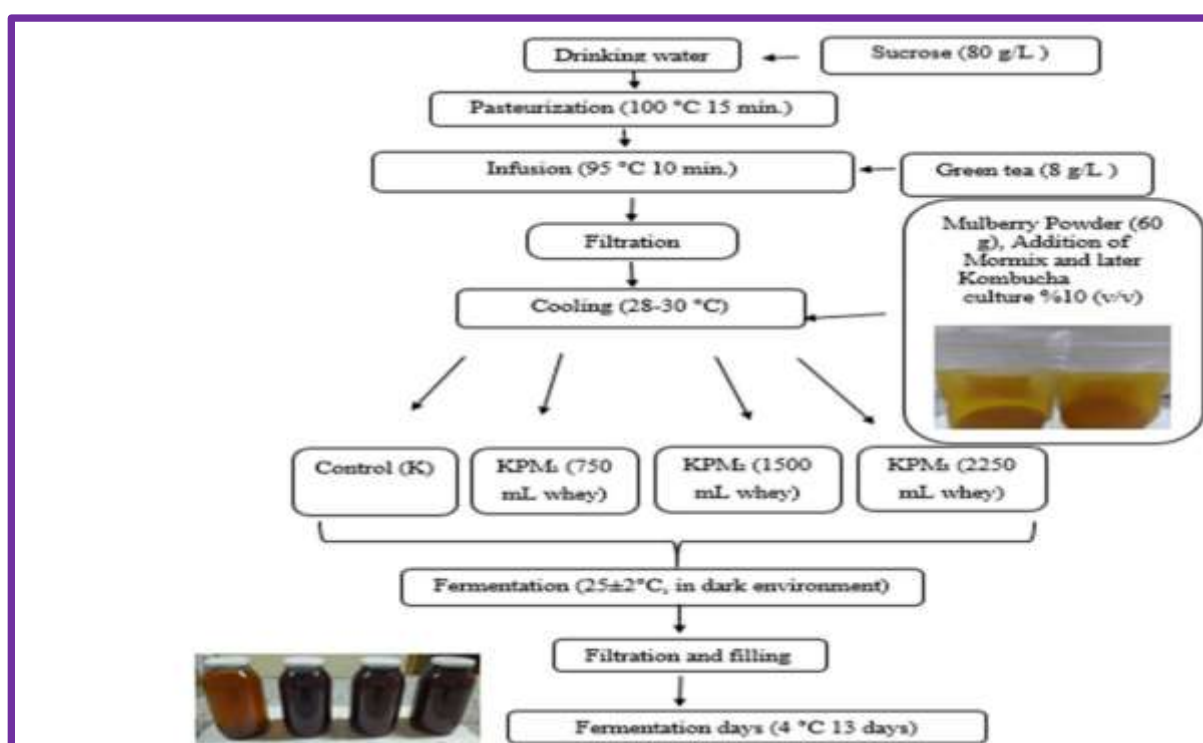


Figure 1. Production flow chart of Kombucha produced with different concentrations of whey, mormix+mulberry powder

### 2.3. Microbiological analyses

The enumeration of acetic acid bacteria was conducted using the pour plate method on Glucose Yeast Extract Calcium Carbonate Agar (GYC) at 30°C for 3-5 days under aerobic conditions, as described by Irigoyen et al. (2004). Following incubation, colonies with a cream color and a clear precipitation zone were identified as typical AAB colonies. *Lactococcus* spp. enumeration was carried out on M17 agar (pH 7.2±0.2) using the pour plate method, with petri dishes incubated at 30°C for 2 days in an aerobic environment, following the method by Irigoyen et al. (2004). For *Lactobacillus* spp. count, MRS agar (pH 6.5±0.2) and the pour plate method were employed, with inoculated petri dishes incubated at 30°C for 3 days in an anaerobic environment using double-layered inoculation according to Irigoyen et al., (2004). Mold counting was performed using Yeast Extract Glucose Chloramphenicol (YGC) agar under aerobic conditions at 25°C for 4 days based on the method by Witthuhn et al. (2005).

## 2.4. Physicochemical and chemical analyses

The dry matter content of Kombucha samples was assessed according to the method in AOAC (1990). Measurement of pH values was conducted using a pH meter (Eutech PH 150 Model), while total acidity was determined as method by Cemeroglu (2007). Viscosity values were measured using a viscometer (Model DV-1; Brookfield Engineering Laboratories, Inc., MA, USA) in line with the procedure detailed by Aktan and Yildirim (2011). Color values ( $L^*$ ,  $a^*$ , and  $b^*$ ) were determined employing a HunterLab device (Colorflex-EZ; HunterLab, Virginia, USA) following the methodology established by Cemeroglu (2007). Furthermore, the Hue angle value ( $\alpha^\circ$ ), Chroma value ( $C$ ), and total color difference values ( $\Delta E^*$ ) were calculated based on Equation 1.

$$C = [(a^*^2 + b^*^2)]^{1/2} \quad \alpha^\circ = \tan^{-1}(b^*/a^*) \quad \Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (\text{Eq.1})$$

## 2.5. Total phenolic contents and antioxidant capacities

The total phenolic content (TPC) of Kombucha samples was determined using a UV spectrophotometer (UV-180, Shimadzu, Kyoto, Japan) based on a colorimetric oxidation/reduction reaction as described by Škerget et al. (2005). The oxidizing reagent used was Folin–Ciocalteu reagent by AOAC guidelines (2019). A 5 mL aliquot of diluted extract (10 mg in 10 mL solvent), 2.5 mL of Folin–Ciocalteu reagent (diluted tenfold with distilled water), and 2.5 mL of  $\text{Na}_2\text{CO}_3$  solution (75 g/L) were combined. The mixture was incubated for five minutes at 50°C and then allowed to cool. A control sample used 0.5 mL of water instead of the extract. The absorbance was measured at 760 nm, and the TPC is expressed as gallic acid equivalents mg GAE  $\text{g}^{-1}$  of dried extract. To determine the antioxidant activities of the Kombucha beverage samples (0.025 mL) were diluted with 4 mL of methanol. After adding a 1 mM 2,2 diphenyl-1-picrylhydrazyl (DPPH) solution prepared with 0.6 mL of methanol, the samples were homogenized by vortexing for 30 min. Samples were measured at 517 nm, and the antioxidant capacity was calculated as % inhibition by Equation (2) below (Chu and Chen, 2006):

$$\text{Inhibition rate (\%)} = [(A_0 - A_1)/A_0] \times 100 \quad (\text{Eq.2})$$

$A_0$ : Absorbance of the blank (control group);  $A_1$ : absorbance of the sample

## 2.6. Sensory analysis

In the sensory evaluation of the Kombucha samples, each sample was subjected to sensory analysis with a panelist group of eight people; the samples were evaluated in terms of color and appearance, odor, sweetness, acidic taste, and general acceptability.

## 2.7. Statistical analyses

The study was set up and conducted according to a randomized complete block experimental plan with 2 replications, 3 different whey concentrations (25%, 50%, and 75%) x 6 different fermentation days (1<sup>st</sup>, 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup>, 11<sup>th</sup>, and 13<sup>th</sup> days). Statistical analyses of the obtained results were performed in the SPSS 22 package program (SPSS Inc., Chicago, IL, USA) and Duncan's multiple comparison test was applied to those whose averages were found significant. The LSD (Least Significant Difference) test was used to determine statistical differences between the obtained average values at a probability level of  $p < 0.05$ .

## 3. Results and Discussion

### 3.1. Acetic acid bacteria (AAB) count

The microbiological analysis results of the Kombucha beverages are shown in *Figure 2a–d*. The lowest number of acetic acid bacteria in the drinks ( $6.87 \log_{10} \text{cfu mL}^{-1}$ ) was detected on the 1<sup>st</sup> day of fermentation in the K sample, and the highest number ( $8.07 \log_{10} \text{cfu mL}^{-1}$ ) was detected on the 7<sup>th</sup> day of fermentation in the KMP<sub>3</sub> sample. Upon examination of the averages based on concentrations, it was observed that the AAB counts of the KMP<sub>3</sub> sample were higher compared to other samples. This difference in the samples is believed to be attributed to the quantity of whey added. Furthermore, fermentation times impacted the AAB counts of the samples, with the highest viability ( $7.65 \log_{10} \text{cfu mL}^{-1}$ ) being recorded on the 9<sup>th</sup> day of fermentation according to the averages. In his study using Kombucha culture to produce fermented milk beverages, Şarkaya (2019) reported that the AAB numbers were close to each other on the 1<sup>st</sup> and 10<sup>th</sup> days of fermentation and that there was an increase in the AAB numbers on the 20<sup>th</sup> and 30<sup>th</sup> days.

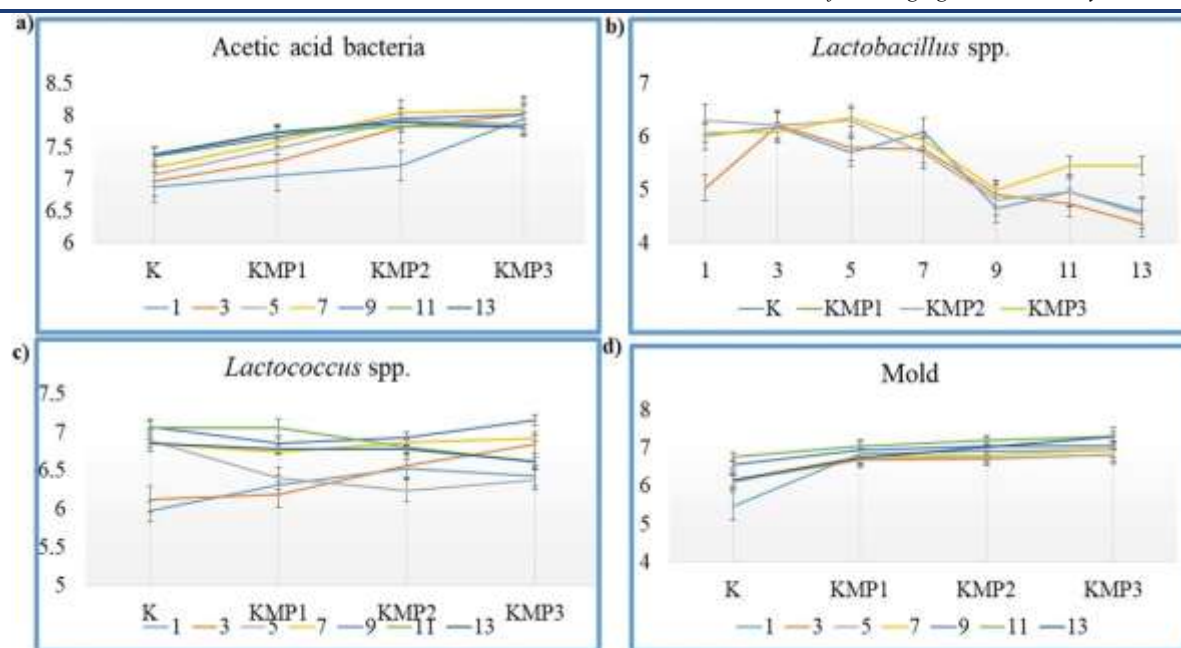


Figure 2a-d. Microbiological changes in Kombucha samples during fermentation ( $\log_{10}$  cfu mL<sup>-1</sup>)

The count of *Lactobacillus* spp. increased in Kombucha beverages with increasing whey concentration. It was determined that there were fluctuations in counts, but the number of living organisms was above 4.00  $\log_{10}$  cfu mL<sup>-1</sup> on all fermentation days. The effect of using different concentrations of whey or mormix+mulberry powder and fermentation time on *Lactobacillus* counts was found to be significant ( $p < 0.05$ ). The lowest *Lactobacillus* count was detected on the 13<sup>th</sup> day of fermentation in the KMP<sub>1</sub> sample (4.36  $\log_{10}$  cfu mL<sup>-1</sup>), and the highest number (6.35  $\log_{10}$  cfu mL<sup>-1</sup>) was detected on the 5<sup>th</sup> day of fermentation in the KMP<sub>3</sub> sample.

The effect of Kombucha beverages on *Lactococcus* spp. was found to be statistically significant ( $p < 0.05$ ). Şarkaya (2019) assessed the lactococci counts of Kombucha samples to be between  $\log$  5.64 and 7.15 cfu mL<sup>-1</sup> and found that their numbers were greater on the 1<sup>st</sup> and 30<sup>th</sup> days of fermentation and lower on the 10<sup>th</sup> and 20<sup>th</sup> days. *Lactococcus* spp. counts in fermented beverages with sage and Kombucha were determined to be between  $\log$  6.55 and 6.56 cfu mL<sup>-1</sup>. It was reported that the sample with the lowest *Lactococcus* count ( $\log_{10}$  cfu mL<sup>-1</sup>) was the green tea sample.

The effect of whey and mormix+mulberry powder addition and fermentation time on mold numbers was found to be significant ( $p < 0.05$ ). The highest number of mold in the beverage samples (7.30  $\log_{10}$  cfu mL<sup>-1</sup>) was detected on the 11<sup>th</sup> day of fermentation in the KMP<sub>3</sub> sample, and the lowest number (5.46  $\log_{10}$  cfu mL<sup>-1</sup>) was detected on the 1<sup>st</sup> day of fermentation in the K sample. Sreeramulu et al. (200) found 4.48  $\log$  cfu mL<sup>-1</sup> mold cells and 5.3  $\log_{10}$  cfu mL<sup>-1</sup> bacterial cells in the fermented liquids after six days of fermentation. Teoh et al. (2004) reported mold counts between 5 and 7  $\log_{10}$  cfu mL<sup>-1</sup> on the sixth day of the process. In addition, Akarca and Tomar (2020) used red carrots, red beets, and purple cabbage in the production of Kombucha tea and reported that the interaction between sample type, fermentation time, and sample type $\times$ fermentation time was highly significant for determining the number of osmophilic molds ( $p < 0.0001$ ). These findings are similar to the findings of the present study. The results are believed to be influenced by the raw materials utilized in the production process. This assumption is supported by the finding of the highest mold count in sample KMP<sub>3</sub>, which had the highest amount of whey. It is speculated that the nutrient-rich composition of whey, combined with mulberry powder, may promote mold growth.

### 3.2. Physicochemical analysis results

The statistical differences in dry matter content, pH, total acidity, and viscosity values of the Kombucha beverages during fermentation are presented in Table 2. It was determined that as the concentration of whey increased, along with the use of mulberry powder and mormix, the dry matter values of the samples also increased. The lowest dry matter content (8.40%) was observed on the 11<sup>th</sup> day of fermentation in the control group (K), while the highest value (18.67%) was recorded on the 13<sup>th</sup> day of fermentation in the KMP<sub>3</sub> group. The findings of this study indicate that the

dry matter values of each sample were statistically influenced by the fermentation days ( $p < 0.05$ ). Naji et al. (2021) reported the dry matter content of iced teas produced with varying concentrations of Hibiscus extract powder to be between 7.50% and 7.84%. Giritlioğlu et al. (2020) found that Kombucha tea samples produced through the fermentation of caper buds and green tea exhibited higher dry matter content compared to the control group containing only capers. The results of these researchers are consistent with the findings of the current study.

**Table 2. Changes in physicochemical parameters determined during fermentation in Kombucha samples**

| Analyses          | Days    | Samples                |                         |                         |                         |                          |
|-------------------|---------|------------------------|-------------------------|-------------------------|-------------------------|--------------------------|
|                   |         | K                      | KMP <sub>1</sub>        | KMP <sub>2</sub>        | KMP <sub>3</sub>        | Average                  |
| Dry matter (%)    | 1       | 8.48±0.23              | 14.46±0.01              | 16.02±0.60              | 17.91±0.72              | 14.22±3.79 <sup>ab</sup> |
|                   | 3       | 8.98±0.94              | 14.20±0.28              | 16.07±0.02              | 16.33±0.05              | 13.89±3.18 <sup>ab</sup> |
|                   | 5       | 8.66±0.47              | 12.59±4.86              | 16.94±0.73              | 18.15±1.11              | 14.08±4.44 <sup>ab</sup> |
|                   | 7       | 8.62±0.63              | 14.31±0.43              | 16.19±0.61              | 17.14±0.24              | 14.06±3.55 <sup>ab</sup> |
|                   | 9       | 8.49±0.14              | 10.96±1.24              | 16.29±0.41              | 17.25±0.35              | 13.24±3.92 <sup>b</sup>  |
|                   | 11      | 8.40±0.14              | 12.02±0.11              | 16.43±0.60              | 17.45±0.63              | 13.57±3.88 <sup>ab</sup> |
|                   | 13      | 8.56±0.20              | 14.32±0.60              | 17.54±0.08              | 18.67±0.10              | 14.77±4.20 <sup>a</sup>  |
|                   | Average | 8.60±0.39 <sup>d</sup> | 13.26±1.95 <sup>c</sup> | 16.49±0.64 <sup>b</sup> | 17.55±0.85 <sup>a</sup> |                          |
| pH                | 1       | 6.47±0.02              | 4.43±0.01               | 4.41±0.00               | 4.38±0.01               | 4.92±0.95 <sup>a</sup>   |
|                   | 3       | 6.04±0.04              | 4.46±0.02               | 4.42±0.02               | 4.39±0.00               | 4.83±0.74 <sup>abc</sup> |
|                   | 5       | 6.04±0.04              | 4.46±0.02               | 4.43±0.02               | 4.40±0.00               | 4.83±0.74 <sup>abc</sup> |
|                   | 7       | 6.05±0.03              | 4.37±0.07               | 4.40±0.03               | 4.62±0.03               | 4.86±0.73 <sup>ab</sup>  |
|                   | 9       | 5.81±0.15              | 4.40±0.00               | 4.49±0.00               | 4.53±0.31               | 4.81±0.63 <sup>bc</sup>  |
|                   | 11      | 5.68±0.25              | 4.25±0.02               | 4.36±0.02               | 4.41±0.01               | 4.67±0.62 <sup>d</sup>   |
|                   | 13      | 5.99±0.01              | 4.27±0.01               | 4.33±0.07               | 4.40±0.07               | 4.75±0.77 <sup>cd</sup>  |
|                   | Average | 6.01±0.25 <sup>a</sup> | 4.38±0.08 <sup>b</sup>  | 4.40±0.05 <sup>b</sup>  | 4.44±0.12 <sup>b</sup>  |                          |
| Total acidity (%) | 1       | 0.45±0.07              | 3.15±0.21               | 3.05±0.07               | 3.40±0.14               | 2.51±1.28 <sup>ab</sup>  |
|                   | 3       | 0.25±0.07              | 2.95±0.07               | 3.05±0.35               | 3.55±0.07               | 2.45±1.38 <sup>abc</sup> |
|                   | 5       | 0.25±0.07              | 2.95±0.07               | 3.05±0.35               | 3.55±0.07               | 2.45±1.38 <sup>abc</sup> |
|                   | 7       | 0.25±0.07              | 2.65±0.07               | 3.00±0.14               | 3.35±0.07               | 2.31±1.30 <sup>c</sup>   |
|                   | 9       | 0.50±0.14              | 2.95±0.07               | 3.25±0.07               | 3.60±0.28               | 2.57±1.31 <sup>a</sup>   |
|                   | 11      | 0.35±0.07              | 2.95±0.07               | 3.45±0.01               | 3.65±0.07               | 2.60±1.41 <sup>a</sup>   |
|                   | 13      | 0.35±0.07              | 2.75±0.07               | 3.05±0.01               | 3.35±0.07               | 2.37±1.27 <sup>bc</sup>  |
|                   | Average | 0.34±0.11 <sup>d</sup> | 2.90±0.17 <sup>c</sup>  | 3.12±0.21 <sup>b</sup>  | 3.49±0.15 <sup>a</sup>  |                          |
| Viscosity (cP)    | 1       | 225±35.35              | 150±42.43               | 290±127.2               | 230±155.5               | 223±95.00 <sup>d</sup>   |
|                   | 3       | 270±42.42              | 375±106.6               | 450±70.7                | 587±77.7                | 420±136.65 <sup>c</sup>  |
|                   | 5       | 225±77.78              | 586±93.33               | 435±49.4                | 955±35.3                | 550±289.5 <sup>b</sup>   |
|                   | 7       | 261±69.29              | 555±134.3               | 469±195.1               | 694±149.9               | 494±200.2 <sup>bc</sup>  |
|                   | 9       | 325±7.07               | 502±110.3               | 743±34.6                | 538±36.7                | 527±165.4 <sup>b</sup>   |
|                   | 11      | 347±52.32              | 498±4.94                | 673±45.2                | 790.5±12.0              | 577±182.3 <sup>ab</sup>  |
|                   | 13      | 348±16.26              | 586±3.90                | 690±98.9                | 949±26.8                | 643±236.3 <sup>a</sup>   |
|                   | Average | 285±63.1 <sup>d</sup>  | 464±165.2 <sup>c</sup>  | 535±177.8 <sup>b</sup>  | 677±254.1 <sup>a</sup>  |                          |

K: Control (only green tea); KMP<sub>1</sub>: Green tea+25% Whey+mormix+mulberry powder; KMP<sub>2</sub>: Green tea+50% whey+mormix+mulberry powder and KMP<sub>3</sub>: Green tea+75% whey+mormix+mulberry powder. \*The difference between values with different letters is statistically significant ( $p < 0.05$ ).

The pH of the whey-containing samples was lower than that of the control. It is also thought that the presence of mormix, which is acidic and supplemented with whey, affects this result. The lowest pH was measured as 4.25 in the KMP<sub>1</sub> sample, while the highest was determined as 6.47 in the K sample. Among the tea samples, the Kombucha tea type with the lowest pH values at the beginning and end of fermentation compared to other samples is the KMP<sub>1</sub> sample ( $p < 0.05$ ). Primiani et al. (2018) reported that the lowest pH value of the Kombucha produced from different plants (green tea, rosella, mangosteen peel, cinnamon, and seduhan leaf) on mango peel was 2.57, and the highest value was 3.05 for green tea. This result may be due to increased concentration of other organic acids, especially acetic and lactic acid, during fermentation (Chen and Liu, 2000).

The total acidity varied alongside pH values across different fermentation days. These variations are believed to be attributed to the raw materials used in Kombucha production and the fermentation process. The average total acidity

values for the control group (K), and the groups with 25% whey + mormix + mulberry powder (KMP<sub>1</sub>), 50% whey + mormix + mulberry powder (KMP<sub>2</sub>), and 75% whey + mormix + mulberry powder (KMP<sub>3</sub>) were determined to be 0.34, 2.90, 3.12, and 3.49, respectively. The increase in acidity was notably higher in Kombucha samples containing whey (KMP<sub>3</sub> and KMP<sub>2</sub>) and relatively lower in the Kombucha tea made solely with green tea (K). Significant differences were observed in the samples on the 9<sup>th</sup> day of fermentation ( $p < 0.05$ ). It is thought that the differences in acidity values occurred as a result of the microbial activity from molds and acetic acid bacteria (AAB), combined with varying sugar concentrations and compositions in the samples over different storage times. Cardoso et al. (2020) reported that the predominant organic acid found in Kombucha samples is acetic acid, at 3 g L<sup>-1</sup>, and that this is produced through the oxidation of ethanol during fermentation by acetic acid bacteria. Kallel et al. (2012) noted that the total acidity (in terms of acetic acid) of Kombucha produced from green and black teas was 0.35 and 0.45 g L<sup>-1</sup>, respectively, on the first day, and 5.4 and 8 g L<sup>-1</sup> on the 15<sup>th</sup> day.

The effect of Kombucha samples, fermentation, and the interaction between sample and fermentation on viscosity results was statistically significant ( $p < 0.01$ ). The use of varying amounts of whey in Kombucha production increased the viscosity values of the samples throughout fermentation. The KMP<sub>3</sub> sample exhibited the highest average viscosity value (677 cP). On the first day of fermentation, the lowest viscosity value (150 cP) was recorded for the KMP<sub>1</sub> sample, while on the 5<sup>th</sup> day of fermentation, the highest value (955 cP) was observed for the KMP<sub>3</sub> sample. Akarca and Tomar (2020) measured the viscosity values of red and purple vegetables prepared from Kombucha teas at 50 rpm (cP) for red carrot, red beet, and purple cabbage samples, reporting values of 57.19, 72.50, and 42.38, respectively. Balcioglu (2013) reported viscosity values ranging from 967 to 1515 cP in a study of strawberry fermented milk drinks, emphasizing that both strawberry concentration and fermentation time increased the viscosity of the samples. Additionally, Watawana et al. (2016) noted that the viscosity of Kombucha tea from coconut water increased due to fermentation. It is believed that the differences observed between these studies are due to variations in production methods, raw materials, and fermentation conditions.

### 3.3. Color results

The color values of foods are among the evaluation criteria that affect consumers' preference points. The differences between the Kombucha beverages and the  $L^*$ ,  $a^*$ ,  $b^*$ ,  $C$ ,  $\alpha^\circ$ , and  $\Delta E^*$  values at different fermentation times are shown in Figure 3a-f. As the whey concentration increased, the  $L^*$  values of the beverage samples fluctuated. It is generally thought that the mormix is effective at decreasing the  $L^*$  value as the concentration increases. The lowest  $L^*$  value of the beverage samples (2.69) was detected on the 1<sup>st</sup> day of fermentation in the KMP<sub>3</sub> sample, and the highest value (34.55) was detected on the 13<sup>th</sup> day of fermentation in the K sample.

Watawana et al. (2016) emphasized that the decrease in the  $L^*$  value in Kombucha samples may be due to the decrease in pH affected by fermentation and the breakdown of color pigments and polyphenolic components resulting from the development of microorganisms. Whey and mormix additions caused a decrease in  $a^*$  parameter values, and the lowest  $a^*$  was found in the KMP<sub>2</sub> and KMP<sub>3</sub> groups. It is thought that the presence of whey, especially the mormix, affects these findings. The average  $a^*$  values of the Kombucha samples during the fermentation periods were determined to be between 9.36 and 13.63. Savan (2022) stated that during the first fermentation of Kombucha samples produced with persimmon, the  $a^*$  value decreased in black and oolong tea samples and increased in green tea. Depending on the persimmon concentration, the  $a^*$  value of the samples decreased with the addition of 5% persimmon to green tea and was reported to decrease further with the addition of 10% persimmon. The addition of mormix decreased the  $b^*$  values of the beverage samples. This color difference may be due to the use of the mormix as a raw material. The lowest  $b^*$  values of the beverages were found in the KMP<sub>2</sub> and KMP<sub>3</sub> samples, and the highest value was found in the K sample. Giritlioğlu et al. (2020) reported  $b^*$  values of 4.29, 2.74, and 3.45 for samples produced from Kombucha green tea, a caper bud, and a green tea + caper bud, respectively.

The lowest  $C$  value of the beverage samples (4.60) was detected on the 3<sup>rd</sup> day of fermentation in KMP<sub>2</sub>, and the highest value (52.64) was detected on the 13<sup>th</sup> day of fermentation in the K sample (Figure 3d). The lowest  $\alpha^\circ$  value of Kombucha beverages (-0.03) was determined on the 1<sup>st</sup> day of fermentation in the KMP<sub>1</sub> and KMP<sub>2</sub> samples, and the highest value (86.19) was determined on the 7<sup>th</sup> day of fermentation in the K sample. With increasing mormix+mulberry powder and whey concentration, the  $C$  values in the beverage samples generally increased, and the  $\alpha^\circ$  values were lower than the control. The lowest  $\Delta E^*$  value (5.88) was found in the KMP<sub>2</sub> group on the 3<sup>rd</sup> day of fermentation, and the highest value (62.97) was found in the K group on the 13<sup>th</sup> day of fermentation. An increase in



where concentration caused Kombucha beverages to obtain positive  $\Delta E^*$  values.

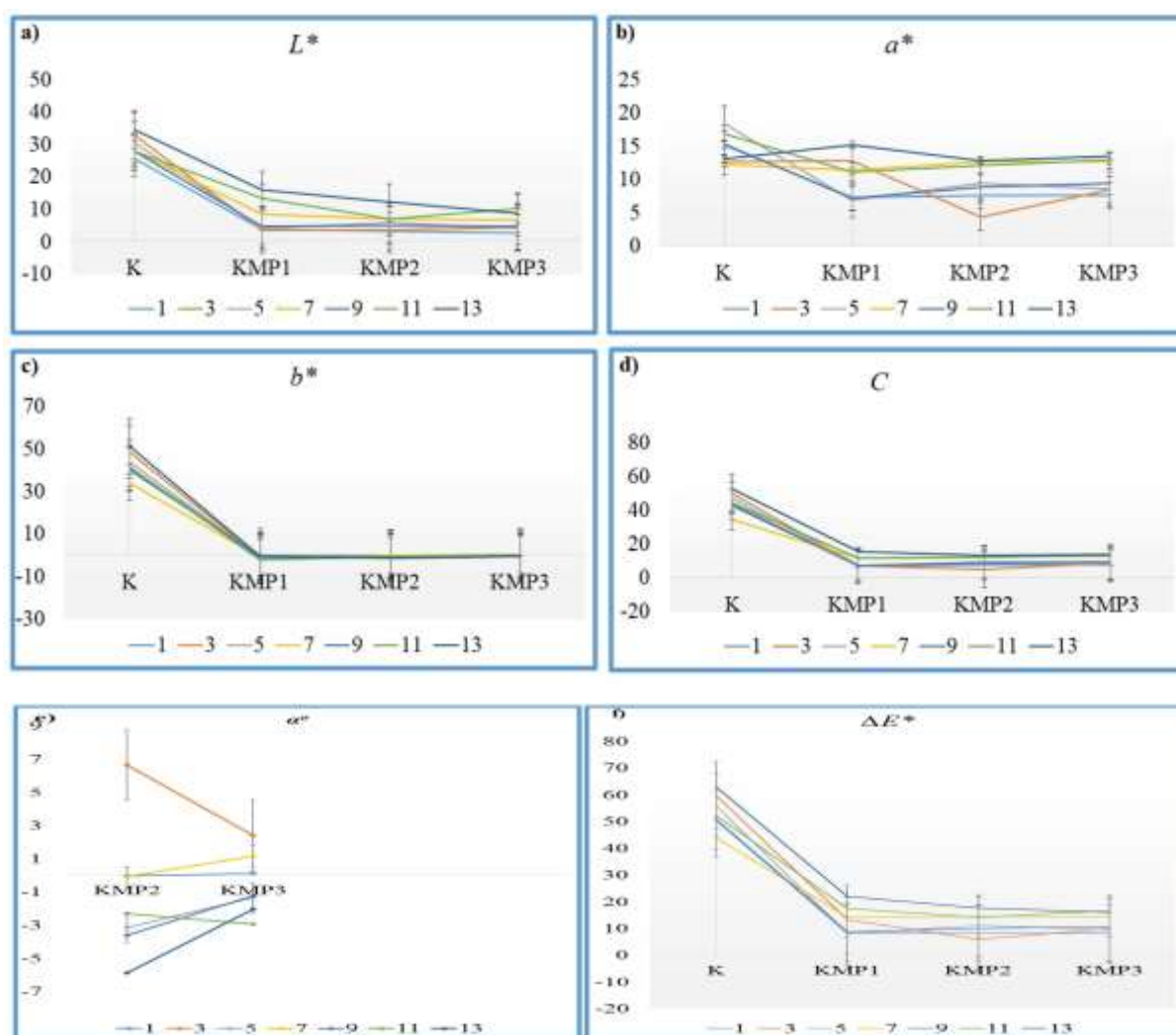


**Figure 3a-f.** Changes in color parameters ( $L^*$ ,  $a^*$ ,  $b^*$ ,  $C$ ,  $\alpha^\circ$ , and  $\Delta E^*$ ) during fermentation in Kombucha samples

### 3.4. Total phenolic content and antioxidant capacity

The effect of enrichment with different concentrations of whey or of mormix+mulberry powder and fermentation on the TPC was determined to be significant ( $p < 0.05$ ). The lowest TPC was found in the K group (981.33 mg GAE g<sup>-1</sup>) on the 5<sup>th</sup> day of fermentation, and the highest value was found in the 1% KMP<sub>1</sub> group (1515.3 mg GAE g<sup>-1</sup>) on the 3<sup>rd</sup> day (Figure 4a). During the fermentation process, the formation of small molecules such as phenolic substances, tannins, and flavonoids with higher antioxidant activity, depending on the activities of microorganisms in the SCOBY culture, can increase the TPC (Chu and Chen, 2006; Jayabalan et al., 2007; Bhattacharya et al., 2016; Gamboa-Gómez et al., 2016; Liamkaew et al., 2016; Ulusoy, 2019). However, long-term fermentation causes a decrease in polyphenol concentration due to microorganisms using phenolic compounds to provide themselves with energy (Watawana et al., 2016).



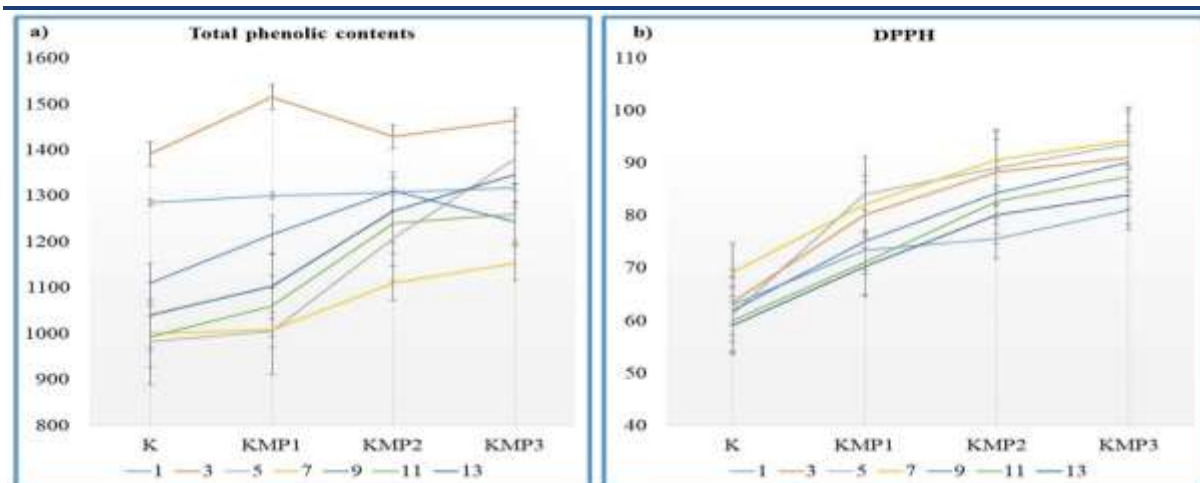


**Figure 4. a) Total phenolic contents (mg GAE g<sup>-1</sup>) and b) Antioxidant capacities (DPPH %) determined in Kombucha samples during fermentation**

Pereira et al. (2014) reported the TPC in Kombucha samples produced with green and black teas as 1080 mg GAE L<sup>-1</sup> and 1120 mg GAE L<sup>-1</sup>, respectively. Bhattacharya et al. (2013) reported that Kombucha species produce Kombucha fruits using black and green tea and sucrose (for a fermentation period of 14<sup>th</sup> days) and that the phenolic compound content in Kombucha beverage samples was greater than that in black and green tea samples. According to the data in Figure 4b, while the concentrations of the components in the control sample decreased, the DPPH values of the Kombucha tea samples increased as the whey concentration increased and with the influence of the mormix. The lowest total antioxidant value (59.03%) of the Kombucha beverage was found on the 13<sup>th</sup> day of fermentation in the K sample, and the highest value (94.29%) was found on the 7<sup>th</sup> day of fermentation in the KMP<sub>3</sub> sample. In different studies, it was determined that the antioxidant capacity and TPC decreased in Kombucha tea samples during fermentation (Chu et al., 2006; Yıkımsı and Tuğgüm, 2019). Differences were observed in the antioxidant rates in the beverages compared to those in the control sample ( $p < 0.05$ ). The reason for this, the presence of lactic acid bacteria in SCOBY may release many bioactive substances in mormix and whey, such as exopolysaccharides, which contribute to the free radical scavenging ability of Kombucha (Amjadi et al. 2023).

Jakubczyk et al. (2020) reported that fermentation time and tea type (green, black, white, or red tea) are effective at enhancing the antiradical properties of Kombucha and in terms of tea type, Kombucha prepared from green tea has the highest antioxidant potential. The results of the present study, which are similar to the findings of previous researchers, suggest that whey and mormix can be used in Kombucha samples together with green tea as good sources of antioxidants.

### 3.5. Sensory results

The results of the sensorial evaluation of the Kombucha samples are given in Table 3. An increase in the mormix+mulberry powder and whey concentrations caused differences in the scores fluctuations given by the panelists regarding color and appearance. In general, color and appearance values were found to be higher than the control group on the 1<sup>st</sup> day of fermentation. The lowest color and appearance score of the samples (5.65) was determined on the 7<sup>th</sup> day of fermentation in the K sample, and the highest score (8.45) was determined on the 1<sup>st</sup> day of fermentation in the KMP<sub>3</sub> sample. With increasing whey concentration, the odor values of the beverage samples differed during fermentation. The panelists gave the lowest odor score (2.95) to the KMP<sub>3</sub> sample, which had the highest whey concentration on the 13<sup>th</sup> day of fermentation, and the highest score (8.35) to the KMP<sub>2</sub> sample on the 9<sup>th</sup> day of fermentation. Giritlioğlu et al. (2020) reported that the odor scores of Kombucha fruits produced with caper buds ranged from 4.85 to 5.65. The researcher stated that since the acid content of Kombucha is a product with a sharp odor, the panelists used scores that were not high and very close to each other when evaluating the odor scores. Differences in taste scores were found throughout the fermentation period for all the samples. Additionally, it was determined that the acidic taste scores of the beverage samples decreased with increasing whey concentration. The lowest acidic taste score of the beverages (2.82 points) was found in the KMP<sub>3</sub> group on the 13<sup>th</sup> day of fermentation, and the highest

Table 3. Changes in sensory parameters of Kombucha samples during fermentation

| Parameters            | Kombucha         | Fermentation Time (days) |                          |                         |                          |                         |                         |                        | Average                 |
|-----------------------|------------------|--------------------------|--------------------------|-------------------------|--------------------------|-------------------------|-------------------------|------------------------|-------------------------|
|                       |                  | 1                        | 3                        | 5                       | 7                        | 9                       | 11                      | 13                     |                         |
| Color and appearance  | K                | 6.90±1.97                | 6.65±2.19                | 7.04±2.62               | 5.65±0.91                | 7.55±0.77               | 7.53±0.66               | 6.03±0.04              | 6.76±1.34 <sup>a</sup>  |
|                       | KPM <sub>1</sub> | 7.30±0.42                | 7.32±0.45                | 7.09±0.12               | 6.60±0.56                | 7.82±1.15               | 8.20±0.28               | 6.15±0.21              | 7.21±0.78 <sup>a</sup>  |
|                       | KPM <sub>2</sub> | 8.23±0.32                | 7.96±0.05                | 5.83±0.24               | 7.47±0.66                | 7.15±1.62               | 7.82±0.25               | 5.88±0.16              | 7.19±1.06 <sup>a</sup>  |
|                       | KPM <sub>3</sub> | 8.45±0.63                | 6.20±0.28                | 5.90±0.14               | 7.20±1.13                | 6.28±1.81               | 7.25±1.76               | 5.73±0.38              | 6.71±1.22 <sup>a</sup>  |
|                       | <b>Average</b>   | 7.72±1.06 <sup>a</sup>   | 7.03±1.11 <sup>abc</sup> | 6.46±1.18 <sup>bc</sup> | 6.73±0.98 <sup>abc</sup> | 7.20±1.22 <sup>ab</sup> | 7.70±0.82 <sup>a</sup>  | 5.94±0.24 <sup>c</sup> |                         |
| Odor                  | K                | 6.86±1.22                | 5.24±1.75                | 5.11±0.16               | 5.28±2.43                | 6.30±0.98               | 6.11±0.16               | 5.67±0.94              | 5.79±1.16 <sup>a</sup>  |
|                       | KPM <sub>1</sub> | 5.79±0.29                | 6.30±1.83                | 7.65±0.49               | 7.79±1.12                | 8.10±1.55               | 6.75±0.35               | 5.89±1.25              | 6.89±1.23 <sup>a</sup>  |
|                       | KPM <sub>2</sub> | 7.63±0.89                | 7.85±1.20                | 4.85±1.20               | 6.30±1.83                | 8.35±0.49               | 7.17±1.17               | 5.75±1.06              | 6.84±1.48 <sup>a</sup>  |
|                       | KPM <sub>3</sub> | 6.25±1.76                | 3.45±0.63                | 3.25±1.76               | 3.40±3.39                | 4.45±0.63               | 3.85±2.61               | 2.95±2.75              | 3.94±1.92 <sup>b</sup>  |
|                       | <b>Average</b>   | 6.63±1.15 <sup>a</sup>   | 5.71±2.03 <sup>a</sup>   | 5.21±1.87 <sup>a</sup>  | 5.69±2.46 <sup>a</sup>   | 6.80±1.84 <sup>a</sup>  | 5.97±1.75 <sup>a</sup>  | 5.06±1.82 <sup>a</sup> |                         |
| Taste                 | K                | 6.06±4.32                | 6.83±3.06                | 4.80±1.69               | 4.90±0.14                | 6.25±1.06               | 6.32±0.96               | 4.68±0.45              | 5.69±1.80 <sup>ab</sup> |
|                       | KPM <sub>1</sub> | 6.87±0.17                | 6.64±1.91                | 5.17±4.00               | 6.82±1.66                | 6.81±0.26               | 7.36±0.50               | 5.90±1.27              | 6.51±1.54 <sup>a</sup>  |
|                       | KPM <sub>2</sub> | 7.30±0.42                | 6.98±0.02                | 5.11±2.99               | 6.57±0.81                | 7.32±0.45               | 5.29±0.41               | 3.83±0.23              | 6.06±1.55 <sup>ab</sup> |
|                       | KPM <sub>3</sub> | 8.42±0.59                | 4.73±1.03                | 5.80±2.54               | 5.85±1.20                | 4.32±0.96               | 3.14±1.61               | 2.83±0.23              | 5.01±2.08 <sup>b</sup>  |
|                       | <b>Average</b>   | 7.16±1.89 <sup>a</sup>   | 6.29±1.72 <sup>a</sup>   | 5.22±2.24 <sup>ab</sup> | 6.03±1.15 <sup>ab</sup>  | 6.17±1.34 <sup>ab</sup> | 5.52±1.82 <sup>ab</sup> | 4.31±1.31 <sup>b</sup> |                         |
| Acidic Taste          | K                | 8.91±0.12                | 7.82±1.66                | 4.67±3.29               | 7.37±2.30                | 7.86±0.19               | 4.80±0.28               | 5.47±2.16              | 6.70±2.11 <sup>a</sup>  |
|                       | KPM <sub>1</sub> | 6.12±0.17                | 6.25±1.06                | 7.82±0.25               | 6.58±0.82                | 7.32±1.86               | 6.89±0.14               | 4.17±0.24              | 6.45±1.29 <sup>a</sup>  |
|                       | KPM <sub>2</sub> | 8.74±1.04                | 4.82±3.08                | 5.39±0.55               | 6.63±0.51                | 5.67±0.95               | 5.17±1.16               | 3.82±1.15              | 5.75±1.84 <sup>a</sup>  |
|                       | KPM <sub>3</sub> | 5.83±1.64                | 3.82±0.25                | 3.43±0.60               | 5.73±3.20                | 3.73±0.38               | 4.79±1.11               | 2.82±1.15              | 4.30±1.58 <sup>b</sup>  |
|                       | <b>Average</b>   | 7.40±1.69 <sup>a</sup>   | 5.67±2.12 <sup>bc</sup>  | 5.32±2.14 <sup>bc</sup> | 6.58±1.65 <sup>ab</sup>  | 6.14±1.90 <sup>ab</sup> | 5.41±1.11 <sup>bc</sup> | 4.07±1.44 <sup>c</sup> |                         |
| General acceptability | K                | 6.82±1.15                | 7.10±1.55                | 6.68±0.44               | 6.80±1.13                | 6.07±0.09               | 5.18±3.08               | 3.95±1.47              | 6.08±1.58 <sup>a</sup>  |
|                       | KPM <sub>1</sub> | 7.17±0.24                | 5.78±0.31                | 7.81±1.14               | 7.57±0.60                | 6.75±0.35               | 8.41±0.57               | 3.82±0.25              | 6.76±1.54 <sup>a</sup>  |
|                       | KPM <sub>2</sub> | 8.09±0.00                | 7.42±0.59                | 5.74±1.05               | 7.41±0.83                | 7.67±0.94               | 4.97±2.87               | 2.76±1.07              | 6.29±2.09 <sup>a</sup>  |
|                       | KPM <sub>3</sub> | 5.82±2.57                | 3.75±1.06                | 3.32±0.96               | 6.41±2.24                | 5.09±1.54               | 4.68±2.38               | 1.73±1.03              | 4.40±2.02 <sup>b</sup>  |
|                       | <b>Average</b>   | 6.97±1.38 <sup>a</sup>   | 6.01±1.71 <sup>a</sup>   | 5.89±1.90 <sup>a</sup>  | 7.05±1.14 <sup>a</sup>   | 6.39±1.22 <sup>a</sup>  | 5.81±2.45 <sup>a</sup>  | 3.06±1.25 <sup>b</sup> |                         |

\*K: Control (only green tea); KPM<sub>1</sub>: Green tea+25% Whey+mormix+mulberry powder; KPM<sub>2</sub>: Green tea+50% whey+mormix+mulberry powder and KPM<sub>3</sub>: Green tea+75% whey+mormix+mulberry powder.

\*The difference between values with different letters is statistically significant ( $p<0.05$ ).

score (8.91) was found in the K group on the 1<sup>st</sup> day of fermentation. Panelists showed a negative approach toward an increase in whey concentration when general acceptability scores were given. In the first days of fermentation, the KMP<sub>2</sub> and KMP<sub>1</sub> samples were especially appreciated. Odor and taste changes, which are thought to be caused by whey during the last days of fermentation, may have negatively affected panelist preferences. Giritlioğlu et al. (2020) reported the highest overall liking scores for Kombucha samples containing a caper bud and green tea in the (5.61 point) sample, which they obtained via fermentation with a caper bud and green tea.

#### 4. Conclusions

This study aimed to prepare a new product with improved nutritional and physiological properties by adding whey and mormix+mulberry powder to Kombucha samples, which are functional products. The effects of whey and mormix+mulberry powder addition and fermentation variables on the number of acetic acid bacteria were found to be statistically significant ( $p<0.01$ ). *Lactobacillus* spp. were 4.36–6.35 log<sub>10</sub> cfu mL<sup>-1</sup>, *Lactococcus* spp. were 5.64–7.15 log<sub>10</sub> cfu mL<sup>-1</sup>, and mold counts were 5.46–7.30 log<sub>10</sub> cfu mL<sup>-1</sup>. Content and fermentation time had a statistically significant effect on the viscosity of the samples ( $p<0.01$ ). The total phenolic content of the Kombucha samples was the highest in the green tea+75% whey+mormix+mulberry powder (KMP<sub>3</sub>) sample. In addition, the antioxidant capacities of the functional drinks were greater than control sample. The KMP<sub>1</sub> sample was more liked than the other samples were. Taken together, the results of the present study suggested that the use of green tea, whey, mulberry powder, or mormix fermented with Kombucha can significantly contribute to the health of these plants, considering the effect of consuming foods with high biological value. Moreover, these newly obtained functional drinks with high nutritional value can be considered a refreshing beverage type, especially in the summer months, because of their color, slight sour taste, and aroma originating from whey.

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#### Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

#### Conflicts of Interest

The authors declare that they have no conflict of interest.

#### Authorship Contribution Statement

Concept: Bebek E., Yangılar, F.; Design: Yangılar, F.; Data Collection or Processing: Bebek E., Yangılar, F.; Statistical Analyses: Yangılar, F.; Literature Search: Bebek E., Yangılar, F.; Writing, Review and Editing: Yangılar, F.

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**Türkiye’de İklim Verileri ile Buğday ve Arpa Verimi Arasındaki Nedensellik İlişkisinin Toda-Yamamoto Testi ile Belirlenmesi**

Determining the Causality Relationship Between Climate Data and Wheat and Barley Yield in Turkey with The Toda-Yamamoto Test

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**Öz**

Bu çalışmanın amacı, uzun dönemli iklim verileri ile buğday ve arpa verimi arasındaki nedensellik ilişkisini incelemektir. Çalışmanın veri seti, Türkiye’de 1970-2023 yılları arasındaki 53 yıllık iklim verileri ile buğday ve arpa verimlerini kapsamaktadır. Sıcaklık, yağış, nem ve karlı gün sayısı ile buğday ve arpa verimi arasındaki nedensellik ilişkisinin belirlenmesinde Toda-Yamamoto nedensellik testinden yararlanılmıştır. Bu amaçla ilk olarak serilerin Augmented Dickey-Fuller (ADF) ile Phillips-Perron (PP) birim kök testi yapılmış, serilerin birinci farkında birim kök içerip içermediği belirlenmiştir. Lagrange Çarpanı (LM) Otokorelasyon Testi, White Değişen Varyans Testi (With Cross) ve Granger Nedensellik testi uygulanmış, serilerde otokorelasyon ve değişen varyans sorunu bulunmadığı tespit edilmiştir. Granger nedensellik testine göre, buğday verimi ile sıcaklık arasında %1, buğday verimi ile karlı gün sayısı arasında %5 düzeyde nedensellik ilişkisi bulunmuştur. Arpa verimi ile sıcaklık ve karlı gün sayısı arasında %5, arpa verimi ile nem değerleri arasında %1 düzeyde nedensellik ilişkisi bulunmuştur. Yapılan analizler sonucunda, buğday ve arpa verimindeki değişimlerin büyük oranda sıcaklık ve nem değişikliklerine bağlı olduğu belirlenmiştir. Sıcaklık, yağış ve karlı gün sayısından buğday verimine doğru %1 anlamlılık düzeyinde tek yönlü nedensellik olduğu belirlenmiştir. Ayrıca, sıcaklık ve yağış ile buğday verimi arasında pozitif, karlı gün sayısı ile buğday verimi arasında negatif bir ilişki olduğu belirlenmiştir. Sıcaklık, nem ve karlı gün sayısından arpa verimine doğru %1 anlamlılık düzeyinde tek yönlü nedensellik ilişkisi saptanmıştır. Sıcaklık ve arpa verimi arasında pozitif, nem ve karlı gün sayısı ile arpa verimi arasında negatif bir ilişki olduğu belirlenmiştir. Bu bulgular ışığında, iklim değişkenlerinin buğday ve arpa veriminde önemli bir etkiye sahip olduğu görülmektedir. Ayrıca, sıcaklık, nem, yağış ve karlı gün sayısı gibi iklim faktörlerinin tarımsal üretim üzerindeki etkilerinin analiz edilmesi, gelecekteki gıda güvenliği ve sürdürülebilir tarım için gerekli önlemlerin alınması önem taşımaktadır.

**Anahtar Kelimeler:** Toda-Yamamoto testi, Buğday ve arpa verimi, İklim değişikliği, Nedensellik analizi, Türkiye

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## Abstract

The aim of this study is to examine the causality relationship between long-term climate data and wheat and barley yields. The data set of the study covers 53 years of climate data and wheat and barley yields between 1970-2023 in Turkey. Toda-Yamamoto causality test was used to determine the causality relationship between temperature, precipitation, humidity and number of snowy days and wheat and barley yields. For this purpose, firstly Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were performed on the series to determine whether the series contained a unit root in the first difference. Lagrange Multiplier (LM) Autocorrelation test, White Heteroscedasticity test (With Cross) and Granger Causality test were applied to determine that there was no autocorrelation or heteroscedasticity problems in the series. According to the Granger Causality test, a causality relationship of 1% was found between wheat yield and temperature, 5% between wheat yield and number of snowy days. A causal relationship of 5% was found between barley yield and temperature and number of snowy days, and 1% between barley yield and humidity values. As a result of the analyses, it was determined that changes in wheat and barley yield were largely dependent on temperature and humidity changes. It was determined that there was a unidirectional causality at a significance level of 1% from temperature, precipitation and number of snowy days to wheat yield. In addition, it was determined that there was a positive relationship between temperature and precipitation and wheat yield, and a negative relationship between number of snowy days and wheat yield. A unidirectional causal relationship at a significance level of 1% was found from temperature, humidity and number of snowy days to barley yield. It was determined that there was a positive relationship between temperature and barley yield, and a negative relationship between humidity and number of snowy days and barley yield. In the light of these findings, it is seen that climate variables have a significant effect on wheat and barley yield. In addition, it is important to analyze the effects of climatic factors such as temperature, humidity, precipitation and number of snowy days on agricultural production, and to take the necessary precautions for future food security and sustainable agriculture.

**Keywords:** Toda-Yamamoto test, Wheat and barley yield, Climate change, Causality analysis, Turkey

## 1.Giriş

Dünya’da 2022 yılında yaklaşık 2.8 milyar ton olarak gerçekleşen tahıl üretimi içerisinde buğday, %28 oran ile ilk sırada yer almaktadır (FAO, 2023). Beslenme açısından büyük öneme sahip olan buğdayın toplam ekim alanı 222 milyon ha olup, üretim miktarı 776 milyon tondur. Buğday ekim alanının %55’ini, üretimin ise %48’ini Hindistan, Rusya, AB ülkeleri, Çin ve ABD oluşturmaktadır. Türkiye’de 2023 yılında 6.8 milyon ha alanda buğday üretimi yapılmıştır (TÜİK, 2023). Türkiye’de son yıllarda buğday üretimi mevsimsel dalgalanmaların etkisiyle yaklaşık 19-21 milyon ton arasında değişmektedir. Türkiye, AB ülkeleri ile kıyaslandığında geniş bir buğday ekim alanına sahiptir. Ancak başta toprak verimliliği olmak üzere sıcaklık, yağış, rüzgâr, nem, gibi faktörlerin etkisiyle mevsimsel dalgalanmalar ve verim düşüklüğü yaşanmaktadır (Taner ve Sade, 2005).

Dünya genelinde tahıl üretimi sıralamasında buğday, çeltik ve mısırın ardından dördüncü sırada arpa yer almaktadır. Arpanın ekolojik sınırlarının esnek olması nedeniyle dünya genelinde yaygın bir şekilde üretildiği görülmektedir (Taşcı ve Bayramoğlu, 2020). Dünyada 2022 yılı arpa ekim alanı 49.8 milyon ha, üretim miktarı ise 151.9 milyon tondur. AB ülkeleri, yaklaşık %22 oran ile arpa ekim alanları ve arpa üretiminde ilk sırada bulunmakta olup bunu %16.4 ile Rusya, %8.7, ile Avusturalya ve %8.0 ile Türkiye izlemektedir. Türkiye’de 2023 yılında yaklaşık 3.3 milyon ha alanda 9.2 milyon ton üretim yapılmıştır (USDA, 2023; TÜİK, 2023).

Dünya’da ve Türkiye’de ekim alanlarının artırılamayacağı dikkate alındığında, buğday ve arpa üretimini artırmanın en önemli yolu birim alandan alınan verimi artırmaktan geçmektedir. Verimi artırmada bazı faktörlere etki etmek mümkün iken sıcaklık, yağış, nem ve karlı gün sayısı gibi faktörlere etki edilememektedir. Dünyada artan nüfusun da etkisiyle birlikte sera gazlarının atmosferde artması küresel sıcaklıklarda ciddi artışlara neden olmaktadır. Bu bağlamda, 1860-1990’lı yıllarda küresel sıcaklığın ortalama 0.3°C-0.5°C derece arasında arttığı ve günümüzde ise sanayi öncesi döneme göre yaklaşık 1.5°C’ye kadar ulaştığı, ilerleyen yıllarda ise 1.4°C-5.8°C’ye kadar artabileceği öngörülmektedir. Bu nedenle, birçok doğal afette artışlar yaşanmakta ve sıcaklık ile yağış rejimlerinde değişimler görülmektedir (Andrady ve ark., 2008; Demir, 2009; Aydın ve Sarptaş, 2018; WMO, 2022).

Dünyada birçok sektör iklim değişikliğinden olumsuz etkilenmektedir. Bunlardan birisi olan tarım sektörü, iklim değişikliğinin yarattığı etkilere karşı en hassas sektörlerdendir. Tarım sektörü, pek çok yönden doğal çevreyi etkilemektedir. Bu etkinin yoğunluğu, doğal koşullara bağlı olarak değişiklik gösterebilmektedir. Bu nedenle iklim değişikliğinin analiz edilerek azaltılmasına yönelik tedbirlerin alınması, üretimin sürdürülebilirliğinde önemli bir rol oynamaktadır (Neset ve ark., 2019; Çetin ve ark., 2020; Uslu ve ark., 2023). Ayrıca küresel iklim değişikliğinin tarım sektöründeki olumsuz etkisi bitkisel ürünlerin verimliliğini, ürün miktarlarını ve kalitelerini de olumsuz yönde etkilemektedir.

Bitkiler sağlıklı büyüüp gelişmeleri için bitki besin maddelerinin yanı sıra sıcaklık, su, nem, karlı gün sayısı ve gün ışığı gibi faktörlere ihtiyaç duyarlar. Son dönemlerde iklimsel değişkenlerin üretim ve verim üzerindeki etkilerini inceleyen çok sayıda çalışma bulunmaktadır. Türkiye’de bu gibi etkilerin devam etmesi durumunda, buğday gibi tahıl ürünlerinin veriminde önemli düşüşler yaşanabileceği öngörülmektedir (Öztürk, 2002). Düşük ve yüksek sıcaklık, don, az ya da aşırı yağış, yüksek rüzgâr hızı ve düşük güneşlenme gibi meteorolojik olayların verimin azalmasında etkili faktörler olduğu belirtilmektedir (TOB, 2021). Tonk ve ark. (2011), 2007-2008 ve 2009-2010 yıllarında Ege Bölgesi’nde yaptıkları denemede yüksek yağış miktarının buğday veriminde azalmaya neden olduğunu belirlemişlerdir. Sayılğan (2016), normal koşullarda buğday gelişme döneminde optimum sıcaklık değerlerinin üzerindeki ortalama 1°C’lik artışın yazlık buğday veriminde 5.7 kg/da azalmaya neden olduğunu belirtmektedir. Benzer şekilde Mina ve ark. (2018), yüksek sıcaklık koşullarında, çeşitli tahılların veriminde azalma meydana geldiğini ifade etmektedirler. 2050 yılında Türkiye’de iklim değişikliği nedeniyle buğday ve arpa üretiminde verimin %7.6 oranında azalacağı öngörülmektedir (Dellal ve ark., 2011).

İklim değişkenleri ile tarımsal ürünler arasındaki nedensellik ilişkilerinin belirlenmesinde Toda Tamamoto testinin kullanıldığı çalışmalar da söz konusudur. Eştürk (2022), Ardahan ilinde, 1990-2020 yılları arasında küresel iklim verileri (ortalama sıcaklık ve toplam yağış miktarı) ile hayvancılıkta kullanılan tahıllar ve yem bitkilerinin verimliliği arasındaki ilişkileri araştırmıştır. Çalışmada sınır testi ve Toda-Yamamoto nedensellik testi kullanılmış olup, yağış miktarından ot ve yem verimliliğine doğru nedensellik ilişkisi olduğu belirlenmiştir. Kamçı (2022), dünya tahıl üretimi ve veriminin karbondioksit emisyonu üzerine etkisini Toda-Yamamoto testiyle analiz etmiş olup tahıl üretiminden ve veriminden karbondioksit emisyonuna doğru tek yönlü nedensellik ilişkisi olduğu saptanmıştır. Ürkmez ve ark. (2024), Türkiye’de 1969-2018 yılları arasında tarım sektörü aktivitesi ile CO<sub>2</sub>

emisyollarının nedensellik ilişkisini incelenmiş olup Maki eşbütünleşme testi ve Toda Yamamoto nedensellik testi kullanılmışlardır. Analiz sonuçlarına göre tarımsal katma değer ile yapısal kırılmalar altındaki CO<sub>2</sub> emisyonları arasında uzun dönemli nedensellik ilişkisi saptanırken tarımsal katma değer ile CO<sub>2</sub> arasında da tarımsal üretimden CO<sub>2</sub>’ye doğru tek yönlü nedensellik ilişkisi bulunmuştur. Özkurt (2024), Türkiye’de tarımsal üretim miktarının iklim değışikliklerinin göstergesi olarak kabul edilen değışkenlerden nasıl ve ne yönde etkilendiğini ortaya koymuştur. Bu amaçla birim kök testlerinden sonra Varyans Ayırıştırması, Etki-Tepki Fonksiyonu ve Toda Yamamoto nedensellik analizi yapılmıştır. Türkiye’de tarımsal üretim ile sera gazı emisyonu arasında bir nedensellik ilişkisinin yanı sıra kuraklık, ortalama sıcaklık ve yağış değışkenleri ile sera gazı emisyonu arasında da nedensellik ilişkisi olduğunu, yani sera gazı emisyonunun doğrudan ve dolaylı olarak iklim değışikliğini nedeni olduğunu ortaya koymuştur.

Bu çalışmada ise Türkiye’de uzun dönemli (1970-2023) iklim verileri ile buğday ve arpa verimleri arasındaki nedensellik ilişkisi belirlenmeye çalışılmıştır. Buğday ve arpa Türkiye tarımı açısından önemli ürünlerdir. Son dönemlerde gündeme gelen iklim değışkenlerinin tarımsal ürünler üzerindeki etkisinin bilimsel olarak belirlenmesine ihtiyaç vardır. Bu kapsamda sıcaklık, nem, yağış ve karlı gün sayısı gibi iklim faktörlerinin buğday ve arpa verimi üzerindeki nedensellik ilişkisi Toda-Yamamoto testi ile saptanmıştır. Söz konusu iklim değışkenleri ve ürünlerin verimleri arasındaki ilişkinin yönü ve anlamlılık derecesi belirlenmiştir. Çalışmada elde edilecek sonuçların literatüre katkı sağlayacağı ümit edilmektedir.

## 2. Materyal ve Metot

Çalışmada, 1970-2023 yılları arasında Türkiye'deki buğday ve arpa verimi (kg da<sup>-1</sup>) ile sıcaklık, yağış, nem ve karlı gün sayısı gibi iklim verileri arasındaki ilişkiyi incelemek amacıyla 53 yıllık veri seti kullanılmıştır. Araştırmada, iklim verileri Meteoroloji Genel Müdürlüğü’nden (MGM) ve buğday ile arpa verimi ise Toprak Mahsulleri Ofisi (TMO)’inden alınmıştır. Çalışmada verilerin analizinde ise Eviews 10 istatistiksel paket programından yararlanılmıştır.

Serilerin durağanlık düzeylerini belirlemek amacıyla birim kök testi yöntemlerinden Genişletilmiş Dickey-Fuller (ADF) ile Phillips-Perron (PP) testleri uygulanmıştır. Ayrıca, VAR modelleriyle değışen varyansı ve korelasyonu dikkate alan denklem sistemleri tahmini yapılmıştır. Yapılan denklemler arasındaki hem kalıntıların birbirleriyle olan ilişkilerini ortadan kaldırmak hem de MWALD testinin uygulanabilmesi amacıyla Zellner (1962), tarafından geliştirilmiş olan Görünürde İlişisiz Regresyon (SUR) yöntemi kullanılmıştır (Tunçsiper ve Biçen, 2016). Görünürde ilişisiz regresyon yöntemi, denklemlerin hata terimlerindeki değışen varyans ile korelasyonu dikkate alır (Alkan ve Kılıçtekin, 2020). Ayrıca, çalışmada buğday ve arpa verimi ile iklim verileri arasındaki nedenselliği incelemek amacıyla Toda ve Yamamoto (1995) tarafından tavsiye edilen Granger testi kullanılmıştır.

Analizlerde durağan olmayan verilerin kullanılması sahte nedensellik ilişkilerine yol açabileceğinden, serilerin durağanlık koşulunu sağlaması önemlidir. Durağan olmayan verilerin durağan olabilmesi için birinci veya ikinci farkının alınması da bilgi kaybına yol açabilmektedir. Granger, 1969 yılında değışkenler arasındaki nedensellik ilişkisini belirleyen bir analiz yöntemini geliştirmiştir. Bu test, iki veya daha fazla değışken arasında nedenselliği belirlemek için yaygın olarak tercih edilen bir yöntemdir (Jain ve Ghosh, 2013). Granger testinde, durağan olmayan serilerin farkları alınıp durağan hale getirildiği durumlarda, eşbütünleşme ilişkisi de dahil olmak üzere çeşitli ilişkilerin incelenmesine olanak tanır. Bununla birlikte, Granger analizinde kullanılan F-istatistiğinin, değışkenlerin birbirleriyle eşbütünleşme ilişkisinin bulunması durumunda normal olmayan bir dağılım göstererek geçerliliğini yitirdiği gözlemlenmiştir.

Bu sorunlardan dolayı Toda ve Yamamoto (1995), VAR modeline dayalı olarak, seriler arasında durağanlığın seviyesini ve eşbütünleşme ilişkisini göz ardı ederek, seviye değerlerini kullanarak değışkenlerin birbirleri ile olan nedensellik ilişkisini MWALD testi ile tahmin etmeye yarayan Toda-Yamamoto analizi olarak adlandırılan bir analiz geliştirmiştir (Toda ve Yamamoto, 1995; Gazel, 2017; Mert ve Çağlar, 2019).

Toda-Yamamoto modeli, Granger nedensellik testinin farklı bir versiyonudur. Bir serinin I(0), I(1), I(2) olmasına veya başka bir dereceden eşbütünleşik olup olmamasına bakılmaksızın uygulanabilir bir testtir. Ayrıca, durağanlık seviyelerine sahip seriler için optimal yöntem olarak değerlendirilmektedir (Jain ve Ghosh, 2013; Yuan ve ark., 2014). Testin prosedür adımları şu şekildedir.

1. İlk adımda analiz için kullanılacak serilerin maksimum bütünleşme derecesinin ( $d_{max}$ ) belirlenmesi için birim kök testi yapılır.

2. Seçim kriterlerine dayanarak VAR modeli oluşturulur ve optimum gecikme uzunluğu (k) belirlenir.

3. Değişkenin seviyesinde maksimum bütünleşme derecesi ile gecikme uzunluğu toplanıp VAR (k+d<sub>max</sub>) modeli oluşturulur.

4. VAR modelinin güvenilirliğini doğrulamak için otokorelasyon, normallik, değişen varyans ve spesifikasyon hataları gibi çeşitli testler uygulanarak modelin güvenilirliği kontrol edilir.

5. Analizde kullanılan her bir verinin ilk “k” gecikme derecesi ile birlikte anlamlılıklarını belirlemek amacıyla MWALD testi yapılır. Test sonucu anlamlı ise Toda-Yamamoto testi ile nedenselliğin yönü belirlenir.

Toda-Yamamoto testinde, sıfır hipotezi reddedilerek nedenselliğin olduğu sonucuna varılır. Ayrıca yapılan bu teste göre, Y ve X değişkenleri için tahmin edilen VAR (k+d<sub>max</sub>) modeli aşağıdaki gibi kullanılır (Gazel, 2017).

$$Y_t = \omega \sum_{i=1}^k a_{1i} X_{t-i} + \sum_{i=1}^k \beta_{1i} Y_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{1i} X_{t-i} + \sum_{j=k+1}^{d_{max}} \theta_{1i} Y_{t-i} + \varepsilon_{1t} \quad (\text{Eş. 1})$$

$$X_t = \varphi \sum_{i=1}^k a_{2i} X_{t-i} + \sum_{i=1}^k \beta_{2i} Y_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2i} X_{t-i} + \sum_{j=k+1}^{d_{max}} \theta_{2i} Y_{t-i} + \varepsilon_{2t} \quad (\text{Eş. 2})$$

Denklemlerde verilen  $\varepsilon_{1t}$  ve  $\varepsilon_{2t}$  olarak gösterilen hata terimlerinin beyaz gürültü süreci sergilediği, sıfır ortalama ve sabit kovaryans matrisine sahip olduğu varsayılmakta olup, iki denklemde de dikkate alınarak kullanılacak modelin hipotezleri aşağıda verilmiştir;

H0: İklim değişkeni verilerinden (X), buğday ve arpa verimine (Y) doğru nedensellik ilişkisi yoktur.

H1: İklim değişkeni verilerinden (X), buğday ve arpa verimine (Y) doğru nedensellik ilişkisi vardır.

Değişkenlerin karşılıklı nedensellik ilişkisini belirlemek için, katsayıların sıfıra eşit olup olmadığını  $H_0: \alpha_{1i} = 0$  ve  $H_0: \alpha_{2i} = 0$  şeklinde ifade edilen hipotezler ile düzeltilmiş (modified) WALD test istatistiği kullanılarak değerlendirilir. MWALD test istatistiği, k serbestlik derecesi  $\chi^2$  tablosundaki değerden büyük olması durumunda hipotezler reddedilir (Gazel, 2017).

### 3. Araştırma Sonuçları ve Tartışma

Buğday ve arpa, ekiliş alanı ve üretim açısından Türkiye için büyük öneme sahiptir. 2023 yılında, yaklaşık 6.8 milyon ha alanda 17.3 milyon ton buğday, aynı yılda 3.3 milyon ha alanda ise 9.2 milyon ton arpa üretilmiştir. Bu araştırmada, 1970-2023 yıllarındaki iklim değişkenleri (yağış, sıcaklık, nem ve karlı gün sayısı) ile buğday ve arpa verimi arasındaki nedensellik ilişkisi incelenmiştir. 1970 yılında 116 kg/da olan buğday verimi, 2023 yılında 318 kg/da yükselmiştir. Ayrıca, 1970 yılında 125 kg/da olan arpa verimi 2023 yılında 278 kg/da çıkmıştır. Her iki ürünün verim artışında birçok faktörün etkisi bulunmaktadır. Bunların çoğunluğu kontrol edilebilir (tohum, gübre, ilaç vs.) değişkenler iken, iklim değişkenlerinin kontrol edilebilme durumu söz konusu değildir. Çalışmada iklim verileri ile buğday ve arpa verimlerine ait serilerin durağanlık düzeylerini belirlemek amacıyla Genişletilmiş Dickey-Fuller (ADF) ve Phillips-Perron (PP) birim kök testleri uygulanmıştır. Bu testler, serilerin otokorelasyon sorunları içerip içermediğini anlamak ve durağanlık seviyelerini tespit etmek için kullanılmıştır. Testler, sabit ve sabit + trend koşulları altında gerçekleştirilmiştir. Elde edilen sonuçlara göre, karlı gün sayısı (KGS) ve yağış düzeyinde (I(0)) durağanlık göstermiştir. Nem ve sıcaklık verileri ise düzeyde durağan bulunmamış, ancak birinci farkları alındığında (I(1)) durağanlık kazanmıştır. Tüm serilerin test sonuçlarına ilişkin bilgiler ise *Tablo 1* ile *Tablo 2*'de verilmiştir.

*Tablo 1* ve *Tablo 2*'ye göre, buğday ve arpa verimleri ile iklim verileri (sıcaklık, yağış, nem, karlı gün sayısı) incelendiğinde, sabit durumda karlı gün sayısı (KGS) ve yağış miktarının hem ADF hem de PP birim kök testinde durağanlık göstermektedir. Bu iki değişkenin I(0) seviyesinde olması, fark almadan doğrudan modele dahil edilebileceği anlamına gelir. Ancak nem ve sıcaklık için aynı durum geçerli değildir; bu değişkenler durağanlık göstermediği için I(1) olarak değerlendirilmiştir. Tüm değişkenlerin birinci farkları alındığında hem sabit hem de sabit + trend durumunda durağan oldukları ve farklı düzeylerde durağanlık özellikleri sergiledikleri ortaya konmuştur. Toda-Yamamoto modelinde, düzeyde durağan olan I(0) seriler (karlı gün sayısı ve yağış) fark almadan doğrudan modele dahil edilirken, I(1) seriler (nem ve sıcaklık) de fark alma işlemi uygulanmadan seviyelerinde

kullanılır. Bu yaklaşım, bilgi kaybını önlemek ve nedensellik ilişkilerini doğru bir şekilde incelemek için tercih edilir. Farklı entegrasyon derecelerine sahip serilerin  $I(0)$  ve  $I(1)$  aynı modelde yer alması, istatistiksel tutarlılığı olumsuz etkileyebileceğinden, modele en yüksek entegrasyon derecesi kadar ek bir gecikme ( $d_{\max}$ ) eklenir. Bu çalışmada en yüksek entegrasyon derecesi  $I(1)$  olduğu için  $d_{\max}$  1 olarak belirlenmiştir. Böylece, karlı gün sayısı ve yağış gibi  $I(0)$  serilere de bir gecikme eklenerek modelin tutarlılığı sağlanmıştır. Yani, modelde fark alma işlemi uygulamadan  $d_{\max}$  yalnızca ek gecikme sayısını belirlemek için eklenmiştir. Bu doğrultuda, Bootstrap Toda-Yamamoto nedensellik testinde maksimum bütünleşme derecesi ( $d_{\max}$ ) 1 olarak belirlenmiştir (Dinç, 2022). ADF ve PP testleri birlikte kullanılarak serilerin durağanlık özellikleri daha sağlam temellere dayandırılmış ve sonuçlar karşılaştırılarak doğrulanmıştır.

**Tablo 1. Buğday ve arpa verimlerinin birim kök testleri**

*Table 1. Unit root tests of wheat and barley yields*

| Düzy |             | Seriler | ADF        | PP         | Birinci Farklar | Seriler | ADF         | PP          |
|------|-------------|---------|------------|------------|-----------------|---------|-------------|-------------|
|      |             |         |            |            |                 |         |             |             |
|      | Sabit       | Arpa    | -1,8574    | -2,8997*   |                 | Arpa    | -12,7148*** | -46,8245*** |
|      |             | Buğday  | -0,2830    | -1,2428    |                 | Buğday  | -7,2686***  | -20,0108*** |
|      | Sabit+Trend | Arpa    | -6,8871*** | -6,8878*** |                 | Arpa    | -12,5876*** | -52,4489*** |
|      |             | Buğday  | -2,8738    | -5,5551*** |                 | Buğday  | -7,1860***  | -20,2457*** |

\*, \*\*, \*\*\* sırasıyla %10, %5 ve %1 anlamlılık düzeyini göstermektedir.

**Tablo 2. İklim verilerinin birim kök testleri**

*Table 2. Unit root tests of climate data*

| Düzy |             | Seriler  | ADF        | PP         | Birinci Farklar | Seriler  | ADF         | PP          |
|------|-------------|----------|------------|------------|-----------------|----------|-------------|-------------|
|      |             |          |            |            |                 |          |             |             |
|      | Sabit       | KGS      | -6.8426*** | -6.8426*** |                 | KGS      | -12.0775*** | -34.7289*** |
|      |             | Nem      | -1.8609    | -3.9540*** |                 | Nem      | -9.5722***  | -14.4992*** |
|      |             | Sıcaklık | -1.9338    | -3.4076**  |                 | Sıcaklık | -6.5683***  | -24.4234*** |
|      |             | Yağış    | -7.0853*** | -7.0832*** |                 | Yağış    | -8.8373***  | -46.2865*** |
|      | Sabit+Trend | KGS      | -7.2834*** | -7.3074*** |                 | KGS      | -11.9635*** | -41.9997*** |
|      |             | Nem      | -4.7875*** | -4.7875*** |                 | Nem      | -9.4504***  | -14.0328*** |
|      |             | Sıcaklık | -6.9011*** | -6.9006*** |                 | Sıcaklık | -6.5848***  | -29.6520*** |
|      |             | Yağış    | -7.0217*** | -7.0177*** |                 | Yağış    | -8.7721***  | -48.8889*** |

\*, \*\*, \*\*\* sırasıyla %10, %5 ve %1 anlamlılık düzeyini göstermektedir.

### 3.1. Buğday verimindeki değişkenlerin analizi: sıcaklık, yağış ve karlı gün sayısı

Buğday verimi ile sıcaklık, yağış ve karlı gün sayısı (KGS) arasında nedensellik ilişkisi bulunurken, nem ile buğday verimi arasında ilişki bulunmamıştır. Oluşturulan VAR modeli üzerinden hesaplanan buğday verimi ile sıcaklık, yağış ve karlı gün sayısının (k) gecikme uzunluğu *Tablo 3*’te verilmiştir. Oluşturulan VAR modeline göre, buğday verimi ile sıcaklık, yağış ve karlı gün sayısı için en uygun gecikme uzunluğu  $k=2$  olarak belirlenmiştir. Ayrıca, maksimum bütünleşme derecesi ve gecikme uzunluğu 3 ( $k+d_{\max}=2+1$ ) olarak belirlenmiştir.

Lagrange Çarpanı (LM) otokorelasyon test sonuçları incelendiğinde, buğday verimi ile sıcaklık (0.1565), yağış (0.8067) ve karlı gün sayısının (0.1556) olasılık değerlerinin 0.05’ten büyük olduğu tespit edilmiş ve otokorelasyon sorunu olmadığı belirlenmiştir. White değişen varyans testine göre ise buğday verimi ile sıcaklık (0.1737), yağış (0.4035) ve karlı gün sayısının (0.2492) olasılık değerlerinin 0.05’ten büyük olması, değişen varyans probleminin bulunmadığını göstermektedir. Granger nedensellik testine göre buğday verimi ile sıcaklık arasında %1, buğday verimi ile yağış arasında %10 ve buğday verimi ile karlı gün sayısı arasında %5 düzeyde nedensellik ilişkisi bulunmuştur. Buğday verimi ile iklim verileri için her bir değişkenin 3 gecikme uzunluğuna göre VAR model tekrar oluşturulmuştur. Oluşturulan VAR modeli, değişen varyansı ve korelasyonu dikkate alarak denklem sistemlerinin tahmin edilmesi için kullanılmıştır. Ayrıca, bu denklemler arasındaki kalıntıların birbiriyle olan ilişkilerini gidermek için Görünürde İlişkisiz Regresyon (Seemingly Unrelated Regression) modeli uygulanmıştır (Tunçsiper ve Biçen, 2016). Buğday ile sıcaklığın SUR modeli *Tablo 5*’te verilmiştir.



**Tablo 3. Buğday verimi ile sıcaklık, yağış ve karlı gün sayısının VAR modelinde gecikme uzunluğu seçimi**

Table 3. Lag length selection of wheat yield and temperature, precipitation and snowy days in the VAR model

| Buğday verimi ve sıcaklık VAR modelinin gecikme uzunluğunun seçimi         |                 |                  |                  |                   |                   |                   |
|----------------------------------------------------------------------------|-----------------|------------------|------------------|-------------------|-------------------|-------------------|
| Lag                                                                        | LogL            | LR               | FPE              | AIC               | SC                | HQ                |
| 0                                                                          | 97.01893        | NA               | 7.09e-05         | -3.878324         | -3.801106         | -3.849028         |
| 1                                                                          | 140.7603        | 82.12671         | 1.40e-05         | -5.500421         | -5.268770         | -5.412533         |
| <b>2</b>                                                                   | <b>150.1391</b> | <b>16.84342*</b> | <b>1.13e-05*</b> | <b>-5.719961*</b> | <b>-5.333876*</b> | <b>-5.573481*</b> |
| 3                                                                          | 153.3331        | 5.475507         | 1.17e-05         | -5.687065         | -5.146545         | -5.481993         |
| 4                                                                          | 155.6118        | 3.720262         | 1.26e-05         | -5.616806         | -4.921852         | -5.353142         |
| 5                                                                          | 160.3716        | 7.382662         | 1.23e-05         | -5.647822         | -4.798433         | -5.325565         |
| Buğday verimi ve yağış VAR modelinin gecikme uzunluğunun seçimi            |                 |                  |                  |                   |                   |                   |
| Lag                                                                        | LogL            | LR               | FPE              | AIC               | SC                | HQ                |
| 0                                                                          | 54.92697        | NA               | 0.000395         | -2.160285         | -2.083068         | -2.130989         |
| 1                                                                          | 88.24831        | 62.56252         | 0.000119         | -3.357074         | -3.125423         | -3.269186         |
| <b>2</b>                                                                   | <b>99.65342</b> | <b>20.48263*</b> | <b>8.84e-05*</b> | <b>-3.659323*</b> | <b>-3.273237*</b> | <b>-3.512843*</b> |
| 3                                                                          | 100.3086        | 1.123167         | 0.000102         | -3.522800         | -2.982280         | -3.317727         |
| 4                                                                          | 101.3378        | 1.680407         | 0.000115         | -3.401545         | -2.706590         | -3.137880         |
| 5                                                                          | 102.7975        | 2.263978         | 0.000129         | -3.297858         | -2.448469         | -2.975601         |
| Buğday verimi ve karlı gün sayısı VAR modelinin gecikme uzunluğunun seçimi |                 |                  |                  |                   |                   |                   |
| Lag                                                                        | LogL            | LR               | FPE              | AIC               | SC                | HQ                |
| 0                                                                          | -4.035626       | NA               | 0.004386         | 0.246352          | 0.323569          | 0.275648          |
| 1                                                                          | 32.16236        | 67.96356         | 0.001179         | -1.067851         | -0.836200*        | -0.979963         |
| <b>2</b>                                                                   | <b>39.54236</b> | <b>13.25388*</b> | <b>0.001028*</b> | <b>-1.205811*</b> | <b>-0.819725</b>  | <b>-1.059330*</b> |
| 3                                                                          | 41.15502        | 2.764565         | 0.001136         | -1.108368         | -0.567848         | -0.903296         |
| 4                                                                          | 44.14060        | 4.874421         | 0.001189         | -1.066963         | -0.372009         | -0.803299         |
| 5                                                                          | 45.55349        | 2.191417         | 0.001331         | -0.961367         | -0.111978         | -0.639110         |

(\*) gecikme uzunluğunu vermektedir.

**Tablo 4. Buğday verimi ile sıcaklık, yağış ve karlı gün sayısının (KGS) LM Otokorelasyon, White Değişen varyans ve Granger nedensellik testi sonuçları**

Table 4. LM Autocorrelation, White Heteroscedasticity and Granger causality test results of wheat yield and temperature, precipitation and number of snowy days (KGS)

| Lagrange Çarpanı (LM) Otokorelasyon Testi |                     |                     |           |
|-------------------------------------------|---------------------|---------------------|-----------|
|                                           | Gecikme Uzunluğu    | LM-Test İstatistiği | P-Değeri  |
| Buğday ve Sıcaklık                        | 3                   | 1.703039            | 0.1565    |
| Buğday ve Yağış                           | 3                   | 1.611865            | 0.8067    |
| Buğday ve KGS                             | 3                   | 6.649940            | 0.1556    |
| White Değişen Varyans Testi (With Cross)  |                     |                     |           |
|                                           | Serbestlik Derecesi | Ki-Kare             | P-Değeri  |
| Buğday ve Sıcaklık                        | 42                  | 50.46666            | 0.1737    |
| Buğday ve Yağış                           | 42                  | 43.59279            | 0.4035    |
| Buğday ve KGS                             | 42                  | 47.79051            | 0.2492    |
| Granger Nedensellik Testi                 |                     |                     |           |
|                                           | Serbestlik Derecesi | Ki-Kare             | P-Değeri  |
| Buğday ve Sıcaklık                        | 2                   | 14.03250            | 0.0009*** |
| Buğday ve Yağış                           | 2                   | 4.779080            | 0.0917*   |
| Buğday ve KGS                             | 2                   | 8.685399            | 0.0130**  |

\*, \*\*, \*\*\* sırasıyla %10, %5 ve %1 anlamlılık düzeyini göstermektedir.

VAR modelinin güvenilirliğini doğrulamak için Lagrange Çarpanı (LM) Otokorelasyon Testi, White Değişen Varyans Testi (With Cross) ve Granger Nedensellik testi yapılmış olup, sonuçlara ilişkin bilgiler *Tablo 4*’te verilmiştir.

Sıcaklık ve buğday verimi arasındaki nedensellik ilişkisini test etmek amacıyla SUR modeli oluşturulmuştur. Denklem kısmında belirtilen değişkenler üzerinden analiz yapılmış ve modele ilişkin  $R^2$ , 0.554064 olarak belirlenmiştir. Çoklu belirtme katsayısına göre, diğer faktörler sabitken buğday verimindeki değişimin %55.4’ünün sıcaklık değişkeni tarafından açıklandığı söylenebilir. Bu bulgu, sıcaklık ile buğday verimi arasındaki ilişkinin önemli olduğunu ve sıcaklık değişimlerinin buğday veriminde etkili olduğunu göstermektedir. Ayrıca modelde, sıcaklık ile buğday verimi arasında pozitif yönlü bir ilişki olduğu sonucuna varılmıştır. Bu sonuca göre, sıcaklık, buğday bitkisinin büyüme ve gelişme süreçlerinde önemli bir faktördür. Optimum sıcaklık koşulları, buğday bitkisinin fotosentez verimliliğini, su ve besin alımını artırarak verimi yükseltir. Ancak aşırı sıcaklık stresine maruz kalma, bitki metabolizmasını olumsuz etkileyebilir ve verim düşüşlerine neden olabilir. (Gregory, 2010; FAO, 2022). Buğday verimi ile yağışın Görünüşte İlgisiz Regresyon Modeli sonuçları *Tablo 6*’da verilmiştir.

**Tablo 5. Buğday verimi ile sıcaklığın görünüşte ilgisiz regresyon (SUR) modeli sonuçları**

*Table 5. Seemingly unrelated regression (SUR) model results of wheat yield and temperature*

|                                                                                                                                                                | Katsayı   | Std. Hata | t-istatistik | P-Değeri |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------|--------------|----------|
| C(1)                                                                                                                                                           | 0.171387  | 0.136435  | 1.256181     | 0.2124   |
| C(2)                                                                                                                                                           | 0.057327  | 0.137849  | 0.415870     | 0.6785   |
| C(3)                                                                                                                                                           | 0.069100  | 0.134776  | 0.512701     | 0.6094   |
| C(4)                                                                                                                                                           | 0.089757  | 0.068454  | 1.311197     | 0.1932   |
| C(5)                                                                                                                                                           | -0.063393 | 0.071992  | -0.880552    | 0.3810   |
| C(6)                                                                                                                                                           | 0.124170  | 0.062810  | 1.976906     | 0.0512   |
| C(7)                                                                                                                                                           | 1.015960  | 0.330286  | 3.076000     | 0.0028   |
| C(8)                                                                                                                                                           | 0.441153  | 0.277517  | 1.589645     | 0.1155   |
| C(9)                                                                                                                                                           | 0.450212  | 0.280393  | 1.605648     | 0.1119   |
| C(10)                                                                                                                                                          | -0.092437 | 0.274142  | -0.337189    | 0.7368   |
| C(11)                                                                                                                                                          | 0.440458  | 0.139240  | 3.163301     | 0.0021   |
| C(12)                                                                                                                                                          | 0.194983  | 0.146436  | 1.331524     | 0.1865   |
| C(13)                                                                                                                                                          | 0.137913  | 0.127760  | 1.079470     | 0.2833   |
| C(14)                                                                                                                                                          | -0.828700 | 0.671821  | -1.233512    | 0.2207   |
| Determinant Artık Kovaryans                                                                                                                                    |           |           |              | 1.05E-05 |
| Denklem: LOGSICAKLIK= C(1)*LOGSICAKLIK(-1)+ C(2) *LOGSICAKLIK(-2) + C(3)*LOGSICAKLIK (3) + C(4)*LOGBUGDAY(-1) + C(5)*LOGBUGDAY(-2) + C(6)*LOGBUGDAY(-3) + C(7) |           |           |              |          |
| $R^2$                                                                                                                                                          |           |           |              | 0.554064 |
| Düzeltilmiş $R^2$                                                                                                                                              |           |           |              | 0.493254 |
| R. S. Hatası                                                                                                                                                   |           |           |              | 0.043383 |
| Korelasyon                                                                                                                                                     |           |           |              | 0.579475 |

Yağış ile buğday verimi arasındaki nedensellik ilişkisini test etmek amacıyla SUR modeli oluşturulmuş ve denklemde belirtilen değişkenler üzerinden analiz yapılmıştır. SUR modeline göre,  $R^2$  değeri incelendiğinde, diğer tüm faktörler sabitken buğday verimindeki değişimin %18.3’ünün yağış değişkeni tarafından açıklandığını göstermektedir. Yağış ile buğday verimi arasında düşük düzeyde ve pozitif yönlü bir ilişki olduğunu belirlenmiştir. Bu sonuca göre, yağışın buğday verimi üzerindeki etkisi önemlidir, ancak diğer faktörlerin de (toprak kalitesi, gübre kullanımı, tarım teknikleri vb.) buğday verimini etkileyebileceği göz önünde bulundurulmalıdır. Bu bağlamda, yağış miktarının buğday verimi üzerinde pozitif bir etkisi vardır. Yeterli ve dengeli yağış, toprağın nem seviyesini ideal düzeyde tutar, bitki beslenmesini ve su emilimini kolaylaştırır ve böylece verimi artırabilir. (FAO, 2012; IPCC, 2014). Buğday verimi ile karlı gün sayısının SUR modeli sonuçları *Tablo 7*’de verilmiştir.

**Tablo 6. Buğday verimi ile yağışın Görünüşte İlgisiz Regresyon (SUR) Modeli sonuçları***Table 6. Seemingly Unrelated Regression (SUR) Model results of wheat yield and precipitation*

|                                                                                                                                                     | Katsayı   | Std. Hata | t-istatistik | P-Değeri |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------|--------------|----------|
| C(1)                                                                                                                                                | 0.043259  | 0.135907  | 0.318296     | 0.7510   |
| C(2)                                                                                                                                                | -0.076148 | 0.128964  | -0.590458    | 0.5564   |
| C(3)                                                                                                                                                | 0.063759  | 0.130807  | 0.487425     | 0.6272   |
| C(4)                                                                                                                                                | 0.348270  | 0.167849  | 2.074897     | 0.0409   |
| C(5)                                                                                                                                                | -0.540575 | 0.169763  | -3.184297    | 0.0020   |
| C(6)                                                                                                                                                | 0.140631  | 0.162534  | 0.865238     | 0.3893   |
| C(7)                                                                                                                                                | 6.500384  | 1.503767  | 4.322733     | 0.0000   |
| C(8)                                                                                                                                                | 0.073237  | 0.114607  | 0.639029     | 0.5245   |
| C(9)                                                                                                                                                | -0.127548 | 0.108752  | -1.172830    | 0.2440   |
| C(10)                                                                                                                                               | -0.044362 | 0.110306  | -0.402170    | 0.6885   |
| C(11)                                                                                                                                               | 0.451189  | 0.141544  | 3.187637     | 0.0020   |
| C(12)                                                                                                                                               | 0.244919  | 0.143157  | 1.710843     | 0.0906   |
| C(13)                                                                                                                                               | 0.242822  | 0.137061  | 1.771632     | 0.0799   |
| C(14)                                                                                                                                               | 0.987371  | 1.268093  | 0.778627     | 0.4383   |
| Determinant Artık Kovaryans                                                                                                                         |           |           |              | 7.20E-05 |
| Denklem: LOGYAGIS = C(1)*LOGYAGIS(-1) + C(2)*LOGYAGIS(-2) + C(3)*LOGYAGIS(-3) + C(4)*LOGBUGDAY(-1) + C(5)*LOGBUGDAY(-2) + C(6)*LOGBUGDAY(-3) + C(7) |           |           |              |          |
| R <sup>2</sup>                                                                                                                                      |           |           |              | 0.182888 |
| Düzeltilmiş R <sup>2</sup>                                                                                                                          |           |           |              | 0.071463 |
| R. S. Hatası                                                                                                                                        |           |           |              | 0.109021 |
| Korelasyon                                                                                                                                          |           |           |              | 0.078086 |

**Tablo 7. Buğday verimi ile karlı gün sayısı görünüşte ilgisiz regresyon (SUR) modeli sonuçları***Table 7. Wheat yield and snowy days seemingly unrelated regression (SUR) model results*

|                                                                                                                                             | Katsayı   | Std. Hata | t-istatistik | P-Değeri  |
|---------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------|--------------|-----------|
| C(1)                                                                                                                                        | -0.059569 | 0.142591  | -0.417762    | 0.6771    |
| C(2)                                                                                                                                        | -0.105171 | 0.145946  | -0.720613    | 0.4731    |
| C(3)                                                                                                                                        | -0.104196 | 0.145494  | -0.716156    | 0.4758    |
| C(4)                                                                                                                                        | -0.653055 | 0.564419  | -1.157040    | 0.2504    |
| C(5)                                                                                                                                        | 0.248691  | 0.593617  | 0.418942     | 0.6763    |
| C(6)                                                                                                                                        | -0.397225 | 0.516499  | -0.769073    | 0.4439    |
| C(7)                                                                                                                                        | 8.440503  | 2.034689  | 4.148300     | 0.0001    |
| C(8)                                                                                                                                        | -0.031646 | 0.034465  | -0.918216    | 0.3610    |
| C(9)                                                                                                                                        | -0.033763 | 0.035276  | -0.957127    | 0.3411    |
| C(10)                                                                                                                                       | 0.062454  | 0.035166  | 1.775967     | 0.0792    |
| C(11)                                                                                                                                       | 0.488118  | 0.136422  | 3.578000     | 0.0006    |
| C(12)                                                                                                                                       | 0.275618  | 0.143479  | 1.920959     | 0.0580    |
| C(13)                                                                                                                                       | 0.162293  | 0.124840  | 1.300011     | 0.1970    |
| C(14)                                                                                                                                       | 0.430341  | 0.491791  | 0.875048     | 0.3839    |
| Determinant Artık Kovaryans                                                                                                                 |           |           |              | 0.000796  |
| Denklem: LOGKAR = C(1)*LOGKAR(-1) + C(2)*LOGKAR(-2) + C(3)*LOGKAR(-3) + C(4)*LOGBUGDAY(-1) + C(5)*LOGBUGDAY(-2) + C(6)*LOGBUGDAY(-3) + C(7) |           |           |              |           |
| R <sup>2</sup>                                                                                                                              |           |           |              | 0.164895  |
| Düzeltilmiş R <sup>2</sup>                                                                                                                  |           |           |              | 0.051017  |
| R. S. Hatası                                                                                                                                |           |           |              | 0.369425  |
| Korelasyon                                                                                                                                  |           |           |              | -0.218760 |

Karlı gün sayısı ve buğday verimi arasındaki nedensellik ilişkisini test etmek amacıyla SUR modeli oluşturulmuş ve denklemde belirtilen değişkenler üzerinden analiz yapılmıştır. Buğday verimi ile karlı gün sayısının R<sup>2</sup> değeri incelendiğinde, diğer tüm faktörler sabitken buğday verimindeki değişimin %16.5'inin karlı gün sayısı değişkeni tarafından açıklandığı belirlenmiştir. Karlı gün sayısı ile buğday verimi arasında negatif yönlü

bir ilişki söz konusudur. Bu sonuca göre, karlı gün sayısı arttıkça buğday verimi azalmaktadır, yani aralarında negatif bir ilişki bulunmaktadır. Kar yağışının, buğdayın büyüme dönemine zarar vererek, toprağın su tutma kapasitesini aşırı doldurması sonucu bitki köklerinin çürümeye ya da don olayları nedeniyle bitkinin hasar görmesine neden olabileceği söylenebilir (Özberk ve ark., 2001; Çapar ve Uçan, 2015). Yapılan analizler sonucunda Toda-Yamamoto analizi için gecikme uzunluğu ve maksimum bütünleşme derecesi belirlenmiş olup değişkenler arasındaki ilişkiyi gösteren Görünürde İlişkisiz Regresyon denklem çıktıları da kullanılarak WALD Testi yapılmıştır. Toda-Yamamoto sonuçlarına ilişkin bilgiler *Tablo 8*’de verilmiştir.

**Tablo 8. Buğday verimi ile sıcaklık, yağış ve karlı gün sayısının (KGS) Toda-Yamamoto nedensellik testi sonuçları**

*Table 8. Toda-Yamamoto causality test results of wheat yield and temperature, precipitation and number of snowy days (KGS)*

| Model                             | Denklem                | MWALD    | P-Değeri |
|-----------------------------------|------------------------|----------|----------|
| Buğday verimi=f(Sıcaklık)         | $k = 2$ $d_{\max} = 1$ | 15.21115 | 0.0005   |
| Buğday verimi=f(Yağış)            | $k = 2$ $d_{\max} = 1$ | 10.69266 | 0.0048   |
| Buğday verimi=f(Karlı gün sayısı) | $k = 2$ $d_{\max} = 1$ | 9.790089 | 0.0075   |

İklim verileri ile buğday veriminin gecikme uzunluğu ( $k$ ) ve maksimum bütünleşme derecesi  $d_{\max}$ ’i *Tablo 8*’de gösterilmiştir. Yapılan analiz sonucunda, sıcaklık ile buğday verimi ilişkisinde WALD testi 15.21115 ve P değeri 0.005 olarak elde edilmiştir. Sıcaklık değerlerinden buğday verimine doğru %1 anlamlılık düzeyinde tek yönlü nedensellik ilişkisi bulunmuştur. Sıcaklık değişimlerinin buğday verimini etkilediği ve sıcaklıklarda meydana gelebilecek artış ya da azalışların kayda değer bir etki yaratabileceği öngörülmektedir. Yağış ile buğday verimi arasında WALD testi 10.69266 ve P değeri 0.0048 bulunmuştur. Yağış değerlerinden buğday verimine doğru %1 anlamlılık düzeyinde nedensellik ilişkisi olduğu tespit edilmiştir. Yağış miktarı, buğday veriminin önemli, bir belirleyicisidir. Yani yağışın zamanlaması ve dağılımı da buğday verimi açısından önemlidir. Özellikle ekim öncesi ve büyüme döneminde yetersiz yağış, bitkinin gelişimini olumsuz etkileyebilir. Aşırı yağış ise bitki köklerinde çürümeye neden olabilir, bu da verimi olumsuz etkiler. Karlı gün sayısı ile buğday verimi arasında ise WALD testi 9.790089 ve P değeri 0.0075 bulunmuştur. Karlı gün sayısından buğday verimine doğru %1 anlamlılık düzeyinde tek yönlü nedensel bir ilişki olduğu belirlenmiştir. Yaşanan karlı gün sayısındaki artış veya azalışın buğday verimi üzerinde etkiye sahip olduğu söylenebilir. Kış dönemlerinin uzun sürmesi veya ani don olayları buğday verimini azaltabilmektedir.

### 3.2. Arpa verimindeki değişkenlerin analizi: sıcaklık, nem ve karlı gün sayısı

Arpa verimi ile sıcaklık, nem ve karlı gün sayısı (KGS) arasında nedensellik ilişkisi bulunurken, yağış ile arpa verimi arasında herhangi bir ilişki bulunamamıştır. Oluşturulan VAR modeli sonuçlarına göre, arpa verimi ile iklim verileri için en uygun gecikme uzunlukları belirlenmiştir. *Tablo 9*’a göre sıcaklık için en uygun gecikme uzunluğu  $k=3$ , nem için  $k=2$  ve karlı gün sayısı için  $k=1$  olarak tespit edilmiştir. Maksimum bütünleşme derecesi ile gecikme uzunluğu, sıcaklık için 4 ( $k+d_{\max}=3+1$ ), nem için 3 ( $k+d_{\max}=2+1$ ) ve karlı gün sayısı için 2 ( $k+d_{\max}=1+1$ ) olarak belirlenmiş ve testler yapılmıştır.

VAR modelinin güvenilirliğini doğrulamak için Lagrange Çarpanı (LM) Otokorelasyon Testi, White Değişen Varyans Testi (With Cross) ve Granger Nedensellik testi yapılmış olup, sonuçlara ilişkin bilgiler *Tablo 10*’da verilmiştir.

Lagrange Çarpanı (LM) otokorelasyon test sonuçları incelendiğinde, arpa verimi ile sıcaklık (0.8471), nem (0.3641) ve karlı gün sayısının (0.2474) olasılık değerlerinin 0.05’ten büyük olduğu ve bu nedenle otokorelasyon sorununun bulunmadığı tespit edilmiştir. White değişen varyans testinde ise arpa verimi ile sıcaklık (0.4519), nem (0.1916) ve karlı gün sayısının (0.7488) olasılık değerlerinin 0.05’ten büyük olması, değişen varyans probleminin olmadığını göstermektedir. Granger nedensellik testine göre, arpa verimi ile sıcaklık ve karlı gün sayısı arasında %5, arpa verimi ile nem arasında %1 düzeyde nedensellik ilişkisi bulunmuştur. Arpa verimi ile sıcaklıkta 4, nemde 3 ve karlı gün sayısında 2 gecikme uzunluğuna göre VAR modeli yeniden oluşturulmuştur. Oluşturulan VAR modeli kullanılarak, değişen varyansı ve korelasyonu göz önüne alan denklem sistemlerinin tahmini yapılmıştır. Arpa ile sıcaklığın SUR modeli *Tablo 11*’de verilmiştir.

**Tablo 9. Arpa verimi ile sıcaklık, nem ve karlı gün sayısının VAR modelinde gecikme uzunluğu seçimi**

Table 9. Lag length selection in the VAR model of barley yield, temperature, humidity and number of snowy days

| Arpa verimi ve sıcaklık VAR modelinin gecikme uzunluğunun seçimi         |                  |                  |                  |                   |                   |                   |
|--------------------------------------------------------------------------|------------------|------------------|------------------|-------------------|-------------------|-------------------|
| Lag                                                                      | LogL             | LR               | FPE              | AIC               | SC                | HQ                |
| 0                                                                        | 95.35762         | NA               | 7.59e-05         | -3.810515         | -3.733298         | -3.781219         |
| 1                                                                        | 117.1754         | 40.96407         | 3.67e-05         | -4.537773         | -4.306122*        | -4.449885         |
| 2                                                                        | 121.6798         | 8.089395         | 3.60e-05         | -4.558358         | -4.172272         | -4.411877         |
| <b>3</b>                                                                 | <b>131.7806</b>  | <b>17.31570*</b> | <b>2.81e-05*</b> | <b>-4.807371*</b> | <b>-4.266851</b>  | <b>-4.602298*</b> |
| 4                                                                        | 133.3184         | 2.510764         | 3.12e-05         | -4.706875         | -4.011920         | -4.443210         |
| 5                                                                        | 138.3149         | 7.749653         | 3.02e-05         | -4.747548         | -3.898159         | -4.425291         |
| Arpa verimi ve nem VAR modelinin gecikme uzunluğunun seçimi              |                  |                  |                  |                   |                   |                   |
| Lag                                                                      | LogL             | LR               | FPE              | AIC               | SC                | HQ                |
| 0                                                                        | -66.51707        | NA               | 0.056184         | 2.796615          | 2.873832          | 2.825911          |
| 1                                                                        | -43.77676        | 42.69610         | 0.026154         | 2.031704          | 2.263356          | 2.119593          |
| <b>2</b>                                                                 | <b>-34.67676</b> | <b>16.34285*</b> | <b>0.021263</b>  | <b>1.823541</b>   | <b>2.209627*</b>  | <b>1.970022*</b>  |
| 3                                                                        | -30.45953        | 7.229548         | 0.021128*        | 1.814675*         | 2.355195          | 2.019747          |
| 4                                                                        | -28.60425        | 3.029027         | 0.023165         | 1.902214          | 2.597169          | 2.165879          |
| 5                                                                        | -26.05651        | 3.951598         | 0.024756         | 1.961490          | 2.810879          | 2.283747          |
| Arpa verimi ve karlı gün sayısı VAR modelinin gecikme uzunluğunun seçimi |                  |                  |                  |                   |                   |                   |
| Lag                                                                      | LogL             | LR               | FPE              | AIC               | SC                | HQ                |
| 0                                                                        | -0.374829        | NA               | 0.003777         | 0.096932          | 0.174149          | 0.126228          |
| <b>1</b>                                                                 | <b>12.71913</b>  | <b>24.58458*</b> | <b>0.002607*</b> | <b>-0.274250*</b> | <b>-0.042599*</b> | <b>-0.186362*</b> |
| 2                                                                        | 16.45606         | 6.711225         | 0.002638         | -0.263513         | 0.122573          | -0.117032         |
| 3                                                                        | 20.54548         | 7.010436         | 0.002635         | -0.267163         | 0.273357          | -0.062090         |
| 4                                                                        | 23.94452         | 5.549441         | 0.002712         | -0.242633         | 0.452321          | 0.021031          |
| 5                                                                        | 26.19564         | 3.491546         | 0.002934         | -0.171251         | 0.678138          | 0.151006          |

(\*) gecikme uzunluğunu vermektedir.

**Tablo 10. Arpa verimi ile sıcaklık, nem ve karlı gün sayısı (KGS) LM Otokorelasyon, White Değişen varyans ve Granger nedensellik testi sonuçları**

Table 10. Barley yield and temperature, humidity and number of snowy days (KGS) LM Autocorrelation, White Heteroscedasticity and Granger causality test results

| Lagrange Çarpanı (LM) Otokorelasyon Testi |                     |                     |           |
|-------------------------------------------|---------------------|---------------------|-----------|
|                                           | Gecikme Uzunluğu    | LM-Test İstatistiği | P-Değeri  |
| Arpa ve Sıcaklık                          | 4                   | 1.383071            | 0.8471    |
| Arpa ve Nem                               | 3                   | 4.322574            | 0.3641    |
| Arpa ve KGS                               | 2                   | 5.413488            | 0.2474    |
| White Değişen Varyans Testi (With Cross)  |                     |                     |           |
|                                           | Serbestlik Derecesi | Ki-Kare             | P-Değeri  |
| Arpa ve Sıcaklık                          | 42                  | 42.44252            | 0.4519    |
| Arpa ve Nem                               | 42                  | 49.76638            | 0.1916    |
| Arpa ve KGS                               | 42                  | 35.54019            | 0.7488    |
| Granger Nedensellik Testi                 |                     |                     |           |
|                                           | Serbestlik Derecesi | Ki-Kare             | P-Değeri  |
| Arpa ve Sıcaklık                          | 2                   | 7.964231            | 0.0186**  |
| Arpa ve Nem                               | 2                   | 10.84569            | 0.0044*** |
| Arpa ve KGS                               | 2                   | 8.039683            | 0.0180**  |

\*, \*\*, \*\*\* sırasıyla %10, %5 ve %1 anlamlılık düzeyini göstermektedir.

**Tablo 11. Arpa verimi ile sıcaklığın Görünüşte İlgisiz regresyon (SUR) modeli sonuçları**

*Table 11. Seemingly unrelated regression (SUR) model results of barley yield and temperature*

|                                                                                                                                                                                                        | Katsayı   | Std. Hata | t-istatistik | P-Değeri |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------|--------------|----------|
| C(1)                                                                                                                                                                                                   | 0.235231  | 0.138716  | 1.695774     | 0.0937   |
| C(2)                                                                                                                                                                                                   | 0.029541  | 0.120561  | 0.245032     | 0.8070   |
| C(3)                                                                                                                                                                                                   | 0.063453  | 0.119273  | 0.532001     | 0.5962   |
| C(4)                                                                                                                                                                                                   | 0.108776  | 0.117087  | 0.929022     | 0.3556   |
| C(5)                                                                                                                                                                                                   | 0.042195  | 0.041393  | 1.019374     | 0.3110   |
| C(6)                                                                                                                                                                                                   | -0.057064 | 0.041635  | -1.370558    | 0.1743   |
| C(7)                                                                                                                                                                                                   | 0.208351  | 0.046165  | 4.513142     | 0.0000   |
| C(8)                                                                                                                                                                                                   | -0.046199 | 0.049063  | -0.941629    | 0.3491   |
| C(9)                                                                                                                                                                                                   | 0.669407  | 0.314859  | 2.126054     | 0.0365   |
| C(10)                                                                                                                                                                                                  | 0.145722  | 0.434705  | 0.335220     | 0.7383   |
| C(11)                                                                                                                                                                                                  | 0.497382  | 0.377811  | 1.316486     | 0.1917   |
| C(12)                                                                                                                                                                                                  | 0.021470  | 0.373776  | 0.057440     | 0.9543   |
| C(13)                                                                                                                                                                                                  | 0.184187  | 0.366924  | 0.501974     | 0.6170   |
| C(14)                                                                                                                                                                                                  | 0.200255  | 0.129715  | 1.543803     | 0.1265   |
| C(15)                                                                                                                                                                                                  | 0.157076  | 0.130476  | 1.203866     | 0.2321   |
| C(16)                                                                                                                                                                                                  | 0.003878  | 0.144672  | 0.026807     | 0.9787   |
| C(17)                                                                                                                                                                                                  | 0.195882  | 0.153752  | 1.274017     | 0.2063   |
| C(18)                                                                                                                                                                                                  | 0.215208  | 0.986699  | 0.218110     | 0.8279   |
| Determinant Artık Kovaryans                                                                                                                                                                            |           |           |              | 1.59E-05 |
| Denklem: LOGSICAKLIK = C(1)*LOGSICAKLIK(-1) + C(2) *LOGSICAKLIK(-2) + C(3)*LOGSICAKLIK(-3) + C(4) *LOGSICAKLIK(-4) + C(5)*LOGARPA(-1) + C(6)*LOGARPA(-2) + C(7)*LOGARPA(-3) + C(8) *LOGARPA(-4) + C(9) |           |           |              |          |
| R <sup>2</sup>                                                                                                                                                                                         |           |           |              | 0.650312 |
| Düzeltilmiş R <sup>2</sup>                                                                                                                                                                             |           |           |              | 0.582080 |
| R. S. Hatası                                                                                                                                                                                           |           |           |              | 0.039471 |
| Korelasyon                                                                                                                                                                                             |           |           |              | 0.475529 |

Sıcaklık değerleri ile arpa verimi arasındaki nedensellik ilişkisini test etmek amacıyla SUR modeli oluşturulmuştur. Denklemden belirtilen değişkenler üzerinden analiz yapılmıştır. Yapılan SUR analiz sonucunda elde edilen R<sup>2</sup> değerine göre, diğer tüm faktörler sabitken arpa verimindeki değişimin %65.0'nın sıcaklık değişkeni tarafından açıklandığı belirlenmiştir. Sıcaklık değerleri ile arpa verimi arasındaki ilişkinin önemli olduğu ve sıcaklık değişimlerinin arpa verimi üzerinde etkili olduğu söylenebilir. Ayrıca sıcaklık ile arpa verimi arasında pozitif yönlü bir ilişki söz konusudur. Bu sonuca göre, optimum sıcaklık koşulları arpa bitkisinin fotosentez verimliliğini artırabilmekte olup besin ve su alımını optimize ederek bitki sağlığını desteklemektedir. Ancak aşırı sıcaklıklarda bitki metabolizmasını olumsuz etkileyerek verim düşüşlerine neden olabilir. Bu nedenle, tarımsal üretimde iklim değişikliklerinin dikkate alınması ve sıcaklık stresine dayanıklı arpa çeşitlerinin geliştirilmesi büyük önem taşımaktadır (Haddadin, 2015; Doğan ve Yıldırım, 2023). Arpa verimi ile nem değerleri arasındaki Görünüşte İlgisiz Regresyon Modeli sonuçları Tablo 12’de verilmiştir.

Nem değerleri ile arpa verimi arasındaki nedensellik ilişkisini test etmek amacıyla SUR modeli oluşturulmuş olup denklemden belirtilen değişkenler üzerinden analizler yapılmıştır. SUR analiz sonucunda elde edilen R<sup>2</sup> değerine göre, diğer tüm faktörler sabitken arpa verimindeki değişimin %48.4’ünün nem değişkeni tarafından açıklandığı ve iki değişken arasında negatif yönlü bir ilişki olduğu belirlenmiştir. Bu durum, arpa bitkisinin aşırı nem koşullarında optimal büyüme ve gelişme gösteremediğini ortaya koymaktadır. Aşırı nem, toprağın oksijen seviyesini düşürebilir, bitki köklerinin sağlıklı büyümesini engelleyebilir ve kök çürüklüğü gibi hastalıklara yol açabilir. Ayrıca yüksek nem, bitkinin buharlaşma ve terleme süreçlerini bozarak su alımını zorlaştırabilir. Bu bağlamda, tarımda optimal verimi sağlamak için nem seviyelerinin dikkatlice izlenmesi ve yönetilmesi gereklidir. Özellikle iklim değişikliklerinin bu tür tarımsal parametreler üzerindeki etkilerini anlamak, sürdürülebilir tarım uygulamaları açısından önem taşımaktadır (Aktaş, 2017). Arpa verimi ile karlı gün sayısının SUR modeli sonuçları Tablo 13’de verilmiştir.



**Tablo 12. Arpa verimi ile nemin görünüşte ilgisiz regresyon (SUR) modeli sonuçları***Table 12. Seemingly unrelated regression (SUR) model results of barley yield and moisture*

|                                                                                                                             | Katsayı   | Std. Hata | t-istatistik | P-Değeri  |
|-----------------------------------------------------------------------------------------------------------------------------|-----------|-----------|--------------|-----------|
| C(1)                                                                                                                        | 0.469899  | 0.140369  | 3.347603     | 0.0012    |
| C(2)                                                                                                                        | -0.158937 | 0.143183  | -1.110033    | 0.2700    |
| C(3)                                                                                                                        | 0.299494  | 0.132067  | 2.267744     | 0.0258    |
| C(4)                                                                                                                        | 0.158630  | 1.269680  | 0.124937     | 0.9009    |
| C(5)                                                                                                                        | -3.088599 | 1.227062  | -2.517069    | 0.0136    |
| C(6)                                                                                                                        | 1.056926  | 1.300229  | 0.812877     | 0.4185    |
| C(7)                                                                                                                        | 34.76804  | 12.59703  | 2.760020     | 0.0070    |
| C(8)                                                                                                                        | -0.008173 | 0.016280  | -0.502041    | 0.6169    |
| C(9)                                                                                                                        | -0.015145 | 0.016606  | -0.911989    | 0.3643    |
| C(10)                                                                                                                       | -0.005762 | 0.015317  | -0.376201    | 0.7077    |
| C(11)                                                                                                                       | 0.284345  | 0.147255  | 1.930976     | 0.0567    |
| C(12)                                                                                                                       | 0.197977  | 0.142312  | 1.391146     | 0.1677    |
| C(13)                                                                                                                       | 0.228837  | 0.150798  | 1.517510     | 0.1327    |
| C(14)                                                                                                                       | 3.418887  | 1.460976  | 2.340139     | 0.0215    |
| Determinant Artık Kovaryans                                                                                                 |           |           |              | 0.015532  |
| Denklem: $NEM = C(1)*NEM(-1) + C(2)*NEM(-2) + C(3)*NEM(-3) + C(4)*LOGARPA(-1) + C(5)*LOGARPA(-2) + C(6)*LOGARPA(-3) + C(7)$ |           |           |              |           |
| R <sup>2</sup>                                                                                                              |           |           |              | 0.483544  |
| Düzeltilmiş R <sup>2</sup>                                                                                                  |           |           |              | 0.413118  |
| R. S. Hatası                                                                                                                |           |           |              | 1.155660  |
| Korelasyon                                                                                                                  |           |           |              | -0.221997 |

**Tablo 13. Arpa verimi ile karlı gün sayısı görünüşte ilgisiz regresyon (SUR) modeli sonuçları***Table 13. Barley yield and snowy days seemingly unrelated regression (SUR) model results*

|                                                                                                    | Katsayı   | Std. Hata | t-istatistik | P- Değeri |
|----------------------------------------------------------------------------------------------------|-----------|-----------|--------------|-----------|
| C(1)                                                                                               | -0.032899 | 0.139660  | -0.235562    | 0.8143    |
| C(2)                                                                                               | -0.096489 | 0.141732  | -0.680786    | 0.4977    |
| C(3)                                                                                               | -0.780213 | 0.348246  | -2.240410    | 0.0274    |
| C(4)                                                                                               | 0.032074  | 0.328805  | 0.097546     | 0.9225    |
| C(5)                                                                                               | 7.720165  | 1.771326  | 4.358411     | 0.0000    |
| C(6)                                                                                               | -0.056536 | 0.053049  | -1.065718    | 0.2893    |
| C(7)                                                                                               | -0.003533 | 0.053836  | -0.065618    | 0.9478    |
| C(8)                                                                                               | 0.435436  | 0.132279  | 3.291788     | 0.0014    |
| C(9)                                                                                               | 0.322659  | 0.124895  | 2.583444     | 0.0113    |
| C(10)                                                                                              | 1.510696  | 0.672829  | 2.245289     | 0.0271    |
| Determinant Artık Kovaryans                                                                        |           |           |              | 0.002085  |
| Denklem: $LOGKAR = C(1)*LOGKAR(-1) + C(2)*LOGKAR(-2) + C(3)*LOGARPA(-1) + C(4)*LOGARPA(-2) + C(5)$ |           |           |              |           |
| R <sup>2</sup>                                                                                     |           |           |              | 0.147799  |
| Düzeltilmiş R <sup>2</sup>                                                                         |           |           |              | 0.075271  |
| R. S. Hatası                                                                                       |           |           |              | 0.364689  |
| Korelasyon                                                                                         |           |           |              | -0.180194 |

Karlı gün sayısı ile arpa verimi arasındaki nedensellik ilişkisini test etmek amacıyla SUR modeli oluşturulmuş olup denklemde belirtilen değişkenler üzerinden analizler yapılmıştır. Arpa verimi ile karlı gün sayısının R<sup>2</sup> değerine göre, diğer tüm faktörler sabitken arpa verimindeki değişimin %14.8'inin karlı gün sayısı değişkeni tarafından açıklandığı ve KGS ile arpa verimi arasında negatif yönlü ilişki belirlenmiştir. Bu sonuca göre, karlı gün sayısı arttıkça arpa verimi azalmakta ve karlı günlerin fazla olmasının arpa bitkisinin büyüme sürecine zarar

vermektedir. Kar yağışının bitki köklerinin donmasına, bitkilerin yeterli su ve besin alımını gerçekleştirememesine neden olabileceği düşünülmektedir. Ayrıca, uzun süreli kar örtüsü altında kalan bitkiler güneş ışığı alamadıkları için fotosentez yapamamaktadır. Bu olumsuz koşullar, bitki gelişimini engelleyerek verim düşüşlerine yol açmaktadır (Öztürk ve ark., 2017). Analizlerin sonucunda, Toda-Yamamoto analizinin yapılabilmesi için gecikme uzunluğu ve maksimum bütünleşme derecesi belirlenmiş olup, değişkenler arasındaki ilişkiyi gösteren Görünürde İlişkisiz Regresyon (SUR) denklem çıktıları da kullanılarak WALD Testi yapılmıştır. Toda-Yamamoto sonuçlarına ilişkin bilgiler *Tablo 14*’te verilmiştir.

**Tablo 14. Arpa verimi ile sıcaklık, nem ve karlı gün sayısının Toda-Yamamoto nedensellik testi sonuçları**

*Table 14. Toda-Yamamoto causality test results of barley yield and temperature, humidity and number of snowy days*

| Model                           | Denklem                | MWALD    | P-Değeri |
|---------------------------------|------------------------|----------|----------|
| Arpa verimi=f(Sıcaklık)         | k =3<br>$d_{\max} = 1$ | 27.26580 | 0.0000   |
| Arpa verimi=f(Nem)              | k =2<br>$d_{\max} = 1$ | 8.329983 | 0.0155   |
| Arpa verimi=f(Karlı gün sayısı) | k =1<br>$d_{\max} = 1$ | 8.894968 | 0.0029   |

İklim verileri ile arpa veriminin gecikme uzunluğu (k) ve maksimum bütünleşme derecesi ( $d_{\max}$ ) *Tablo 14*’te gösterilmiştir. Yapılan analiz sonucunda, sıcaklık ve arpa verimi ilişkisine göre WALD testi 27.26580, P değeri ise 0.0000 olarak elde edilmiştir. Sıcaklık değerlerinden arpa verimine doğru %1 anlamlılık düzeyinde tek yönlü bir nedensellik ilişkisi belirlenmiştir. Bu, sıcaklığın arpa bitkisinin fotosentez verimliliğini artırabileceği ve metabolik süreçlerini desteklediği anlamına gelir. Ancak aşırı sıcaklıklar bitki metabolizmasını olumsuz etkileyerek verim düşüşlerine yol açabilir. Nem değerleri ile arpa verimi arasında WALD testi 8.329983 ve P değeri 0.0155 bulunmuştur. Nem değerlerinden arpa verime doğru %5 anlamlılık düzeyinde tek yönlü bir nedensellik ilişkisi bulunduğu tespit edilmiştir. Aşırı nem, toprağın oksijen seviyesini düşürebilir ve bitki köklerinin sağlıklı büyümesini engelleyebilir. Ayrıca yüksek nem, bitki üzerindeki buharlaşma ve terleme süreçlerini bozarak su alımını zorlaştırabilir, bu da verim kaybına neden olabilir. Karlı gün sayısı ile arpa verimi arasında ise WALD testi 8.894968 ve P değeri 0.0029 bulunmuştur. Karlı gün sayısından arpa verimine doğru %1 anlamlılık düzeyinde tek yönlü bir nedensellik ilişkisi olduğu belirlenmiştir. Kar yağışı, bitki köklerinin donmasına ve fotosentez süreçlerinin engellenmesine neden olabilir. Bu durum bitki gelişimini olumsuz etkileyerek verim düşüşlerine yol açmaktadır.

#### 4. Sonuç

Tahıllar içinde önemli bir yere sahip olan buğday ve arpa tarımının bilinen bir yetiştiricilik kültürü söz konusudur. Bu ürünlerin üretim sürecinde kullanılan girdilerin önemli bir kısmı kontrol edilebilirken, maksimum verim için çaba gösterilmektedir. Ancak kontrol edilemeyen iklim değişkenleri verimi etkilemektedir. Bunların başında sıcaklık, yağış, nem ve karlı gün sayısı gelmektedir. Bu çalışmada, 1970-2023 yılları arasında Türkiye’deki buğday ve arpa verimliliği ile sıcaklık, yağış, nem ve karlı gün sayısı gibi iklim verileri arasındaki nedenselliği belirlemek amacıyla Toda-Yamamoto testi yapılmıştır.

Yapılan analizler sonucunda, buğday ve arpa veriminde iklimsel faktörlerin önemli bir rol oynadığı belirlenmiştir. Buğday verimindeki değişimin, diğer değişkenler sabitken, %55.4’ünün sıcaklık değişkeni tarafından açıklandığı ve aralarında pozitif bir ilişki olduğu belirlenmiştir. Buğday verimindeki değişimlerin %18.8’inin yağış değişkeni tarafından açıklandığı ve aralarında pozitif bir ilişki olduğu saptanmıştır. Ayrıca, buğday verimindeki değişimin %16.5’inin ise karlı gün sayısı değişkeni ile açıklandığı ve aralarında negatif yönlü bir ilişki olduğu belirlenmiştir. Bunun yanında, sıcaklık, yağış ve karlı gün sayısından buğday verimine doğru %1 anlamlılık düzeyinde tek yönlü nedensellik ilişkisi bulunduğu belirlenmiştir. Arpa verimi üzerinde yapılan analizlerde ise verimdeki değişimin %65.0’inin sıcaklık değişkeni tarafından açıklandığı ve aralarında pozitif bir ilişki olduğu belirlenmiştir. Arpa verimindeki değişimlerin %48.4’ünün nem değişkeni tarafından açıklandığı ve aralarında negatif bir ilişki olduğu saptanmıştır. Ayrıca, arpa verimindeki değişimin %14.8’inin karlı gün sayısı tarafından açıklandığı ve aralarında negatif yönlü bir ilişki bulunduğu saptanmıştır. Sıcaklık ve karlı gün sayısından arpa verimine doğru %1 anlamlılık düzeyinde, nem değerlerinden ise arpa verimine doğru %5 düzeyde tek yönlü nedensellik ilişkisi olduğu belirlenmiştir.

Sonuç olarak, iklim değişkenlerinin buğday ve arpa veriminde önemli bir etkiye sahip olduğu görülmektedir. Bu etkilerin, iklim değişikliğiyle mücadelede, tarımsal planlama ve tarımsal adaptasyon stratejilerinin geliştirilmesinde

dikkate alınması gerekir. Sıcaklık, nem, yağış ve karlı gün sayısı gibi iklim faktörlerinin tarımsal üretim üzerindeki etkilerinin detaylı bir şekilde analiz edilmesi, gelecekteki gıda güvenliği ve sürdürülebilir tarım uygulamaları için önemlidir. Ayrıca, iklim değişikliklerine dayanıklı buğday ve arpa çeşitlerinin geliştirilmesi için genetik araştırmalara ve tohum ıslah çalışmalarına öncelik verilmelidir. Sürdürülebilir tarım uygulamaları için, çiftçilerin iklim değişikliği konusunda bilinçlendirilmesi ve alınabilecek önlemler hakkında eğitim verilmesi gerekmektedir.

#### **Etik Kurul Onayı**

Bu çalışma için etik kuruldan izin alınmasına gerek yoktur.

#### **Çıkar Çatışması Beyanı**

Makale yazarları olarak aramızda herhangi bir çıkar çatışması olmadığını beyan ederiz.

#### **Yazarlık Katkı Beyanı**

Planlama: Doğar, D., Çiçek, A.; Materyal ve Metot: Doğar, D., Çiçek, A.; Veri toplama ve İşleme: Doğar, D.; İstatistiki Analiz: Doğar, D.; Literatür Tarama: Doğar, D.; Makale Yazımı, İnceleme ve Düzenleme: Doğar, D., Çiçek, A.

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**Evaluation and Potential Analysis of Saving Opportunities in Agricultural Enterprises**

Tarım İşletmelerinde Tasarruf Fırsatlarının Değerlendirilmesi ve Potansiyel Analizi

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Zuhal KARAKAYACI<sup>5</sup>****Abstract**

The primary objective of this study is to assess potential savings opportunities in agricultural enterprises and to determine their feasibility. To this end, face-to-face interviews were conducted with 268 agricultural enterprises in Turkey, selected according to the stratified random sampling method. The results of the interviews revealed the amount of savings accrued by agricultural enterprises and the factors influencing the formation of savings. The data obtained was then used to determine the savings potential of agricultural enterprises using artificial neural networks. The classification analysis in the artificial neural network model enables the prediction of the savings potential of enterprises by classifying them according to all the variables included in the model, in comparison to the classification made with the existing data. This approach allows for the consideration of not only financial indicators but also socio-economic factors, personal factors and environmental factors in determining savings policies, thereby revealing the actual potential of the enterprises. To determine the savings potential of the analyzed enterprises, 29 different models in 9 model classes were tested. Consequently, the model class with the highest accuracy was identified as decision trees. The accuracy of decision trees varies between 82.5% and 85.1%. While 62.69% of the enterprises exhibited high savings because of the modelling process, this value was determined as 60.8% because of the prediction model. Furthermore, the proportion of enterprises with low savings, which was estimated at 32.84% in the data model, was found to be 35.8% in the prediction model. Additionally, the proportion of enterprises with negative savings was determined to be 4.48% in the data model and 3.4% in the prediction model. The study identified the structural, social and economic characteristics of enterprises according to their savings structures and evaluated potential for increasing savings. It was determined that agricultural enterprises should focus on ways to increase savings, increase income, keep expenses under control and make investments for the future. Efficient farming techniques, the formation of agricultural cooperatives and marketing associations, the reduction of energy and input costs, the effective utilization of agricultural machinery, and the investment in renewable energy sources could assist agribusinesses in increasing their economic security and sustainability. All these steps enable agricultural households to have a stronger and more sustainable financial structure and contribute to the economic development of rural areas.

**Keywords:** Savings, Agricultural enterprises, Artificial neural networks

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## Öz

Bu çalışmanın temel amacı tarım işletmelerinde tasarruf fırsatlarının değerlendirilmesi ve potansiyellerinin belirlenmesidir. Bu amaca yönelik olarak Türkiye’deki tabakalı tesadüfi örnekleme yöntemine göre belirlenen 268 tarım işletmesiyle yüz yüze anket yöntemiyle mülakatlar yapılmıştır. Mülakatlar sonucunda tarım işletmelerinin tasarruf miktarları ve tasarrufların oluşumları üzerindeki etkili olan faktörler belirlenmiştir. Elde edilen veriler sonucunda tarım işletmelerinin tasarruf potansiyellerini belirlemek için yapay sinir ağları kullanılmıştır. Yapay sinir ağları modelinde sınıflandırma analizi mevcut verilerle yapılan sınıflandırmaya karşı modele dahil edilen tüm değişkenlerle birlikte işletmeleri sınıflandırarak işletmelerin tasarruf potansiyellerine yönelik tahminlerde bulunmaktadır. Böylece tasarruf politikalarının belirlenmesinde sadece finansal göstergeler değil aynı zamanda sosyo-ekonomik faktörler, kişisel faktörler ve çevresel faktörler de göz önünde bulundurularak gerçek potansiyeller ortaya çıkarılmıştır. İncelenen işletmelerde tasarruf yapma potansiyellerini belirlemek amacıyla 9 model sınıfında farklı 29 model test edilmiştir. Buna göre en yüksek doğruluk payına sahip model sınıfı karar ağaçları olarak belirlenmiştir. Karar ağaçlarının doğruluk payları %82,5-%85,1 arasında değişmektedir. Yapılan modelleme sonucunda işletmelerin %62,69’u yüksek tasarrufa sahip iken tahmin modeli sonucunda bu değer %60,8 olarak belirlenmiştir. Ayrıca veri modelinde %32,84 olarak belirlenen düşük tasarruflu işletmelerin oranı tahmin modelinde %35,8 olarak tespit edilmiş olup negatif işletmelerin oranı veri modelinde %4,48 ve tahmin modelinde %3,4 olarak bulunmuştur. Çalışmanın sonucunda tasarruf yapılarına göre işletmelerin yapısal, sosyal ve ekonomik özellikleri küme halinde gösterilerek tasarruf potansiyellerinin artırılmasına yönelik değerlendirmeler yapılmıştır. Çalışma sonucunda tarım işletmelerinin tasarrufu artırma yolları, gelir artırma, giderleri kontrol altında tutma ve geleceğe yönelik yatırımlar yapma üzerine odaklanması gerekliliği belirlenmiştir. Verimli tarım teknikleri kullanmak, tarım kooperatifleri ve pazarlama birliklerine katılmak, enerji ve girdi maliyetlerini azaltmak, tarım makinelerini etkili bir şekilde kullanmak ve yenilenebilir enerji kaynaklarına yatırım yapmak gibi stratejiler, tarım işletmelerinin ekonomik güvenliği ve sürdürülebilirliklerini artırmalarına yardımcı olabilir. Tüm bu adımlar, tarım hane halklarının daha güçlü ve sürdürülebilir bir finansal yapıya sahip olmalarını sağlar ve kırsal kesimin ekonomik kalkınmasına katkıda bulunabilir.

**Anahtar Kelimeler:** Tasarruf, Tarım işletmeleri, Yapay sinir ağları

## 1. Introduction

Agriculture, a basic sector, has always been strategic due to its direct contribution to the service sector and raw materials to industry. Although the share of the industrial and service sectors in national economies has increased with the new market conditions, agriculture provides nutrition and food sources for necessities in many areas. For this reason, as the economy becomes more globalized, the agricultural sector has begun to meet international standards, just like other sectors. This change has also affected the financing sources used by agricultural enterprises, which are the smallest structure in the agricultural sector (Njegomir et al., 2017; Săzrbulescu et al., 2015).

Financing sources in the agricultural sector are examined in two sections: internal and external financing sources. Internal financing in agricultural enterprises consists of two components: auto finance and equity capital. Auto financing is the fund created with the income generated by the enterprises and their internal resources, and while reducing the demand for external financing sources, it also contributes to the independent decision-making of enterprises, ensuring their financial security and reducing the debt burden and interest costs. However, the structural issues in agriculture necessitate the inclusion of external financing sources in the development of financing strategies. To benefit from the financial benefits, particularly in the context of corporate development and expansion, it is essential to use foreign cash. Therefore, rational capital utilization necessitates a balance between financing models, with auto financing instruments being the primary choice due to their ability to manage interest burdens, financial risks, cash flow challenges, and safeguard the enterprise's credit rating (Naranchimeg et al., 2023; Гринюк et al., 2023).

Internal borrowing, stock increases, asset sales, and dividend sales are all commonly used as auto financing instruments. However, the auto financing instruments that enterprises can use may differ according to the size, sector, financial situation, and objectives of the enterprise. Considering the structural and economic characteristics of the agricultural sector, savings come to the forefront among self-financing instruments.

Savings in the agricultural sector refers to income that is not consumed in the current year but is held for future investment, consumption, or unforeseen circumstances (Bayramoğlu et al., 2023; Erdem, 2017; Karagöl and Özkan, 2014; Sancak and Demirci, 2012; Zengin et al., 2018). Savings serve as a strategy to mitigate unforeseeable future risks. Therefore, saving is a crucial economic practice for households to maintain their financial stability. Subsistence farmers make up a significant portion of agricultural enterprises. Subsistence farming enterprises have very limited capital and are defined as enterprises that use traditional methods in carrying out production activities and have low land and labor productivity. For this reason, the social purpose of subsistence farms takes precedence over the profit purpose. In recent years, there have been difficulties in meeting the basic needs of family members in enterprises due to increasing population pressure, climatic differences, market uncertainties, and input costs. Because of this, agricultural enterprises' income decreases, resulting in negative savings (Loiko et al., 2019; Uddin et al., 2014; Wang et al., 2009).

Many studies have been conducted so far to solve the paradox caused by the increase in income and decrease in savings. These studies have analyzed the saving behavior of rural and urban households and the factors affecting these behaviors. In particular, Hamaker and Patrick (1996), in their study in Indiana, showed that agricultural operators maintained their current behavior towards savings, while Spence and Mapp (1976) conducted a study to measure the savings behavior of farmers in Oklahoma. Léon and Rainelli (1976) found that climatic factors, natural disasters and uncertainty in agricultural markets force agricultural operators to save more than operators in other sectors. Jensen and Pope (2004) find a significant relationship between increased saving tendencies and greater income risk. Mapesa (2015) finds that the existence of financial programs increases savings, while Teshome et al. (2013) find that savings channels in the agricultural sector are informal sources. Nayak (2013) found that the lowest income groups (agricultural sector) have the highest marginal propensity to consume and therefore the lowest marginal propensity to save. Maheshwari (2016) stated that rural communities tend to save less. Gikonyo et al. (2022) argue that household savings provide an opportunity to build sufficient capital for farm investments and are useful for technology adoption. Argue that saving is the most important strategy to cope with risk in rural households in Nyando, while other studies (Abegunde et al., 2019; Aryal et al., 2018; Kurgat et al., 2020; Pagliacci et al., 2020; Sönmez and Artukoğlu, 2021; 2022) reveal that household savings in the agricultural sector are not sufficient. As can be understood from the literature, empirical models have been used to examine saving behavior

and the factors affecting it and saving enterprises have been identified with the help of financial data. However, savings, which is the portion of income remaining from expenditures, is constantly changing due to the socio-economic and structural characteristics of agriculture and differs from firms in other sectors. Therefore, the main objective is to classify agricultural enterprises by taking these differences into account and the savings potential of agricultural enterprises has been quantitatively measured by considering economic, social and environmental factors.

## 2. Materials and Methods

Konya province, which is the research region, is considered the capital of agriculture due to its ecological and geographical characteristics. Konya, which is considered the province with the highest capital mobility due to its economic and structural characteristics, has a total population of 106,833 enterprises. For this reason, the stratified random sampling method was used for sampling. Consequently, (Yamane, 1967) determined the number of samples to be 268. After determining the number of samples, a model was created to determine the savings potential of agricultural enterprises. The most appropriate method for this model was determined to be artificial neural networks. As a matter of fact, artificial neural networks, which have advantages such as learning, generalization, nonlinearity, fault tolerance, adaptation, and parallelism, are used in medical applications such as image and signal processing, disease prediction, and in many different application areas such as engineering, production, finance, optimization, and classification (Altaş and Gülpınar, 2012; Karahan, 2011; Sabancı et al., 2012; Taner et al., 2015; Yüksek, 2007). In this study, the savings potential of agricultural enterprises was classified with the help of artificial neural networks.

Classification analysis in artificial neural networks model makes predictions about the savings potential of enterprises by classifying enterprises with all variables included in the model against the classification made with existing data (Akal and Umut, 2022; Baitu et al., 2023; Bayramoğlu et al., 2023; Kayabasi et al., 2018; Kujawa and Niedbała, 2021). For example, because of the classification of enterprises with savings potential with existing financial data using artificial neural network methodology, it can be determined that the savings potential will be low or non-existent. In this way, not only financial indicators but also socio-economic factors, personal factors and environmental factors are taken into consideration in determining savings policies and real potentials are revealed.

In order to assess the potential for cost reductions in the evaluated businesses, a total of 29 distinct models from 9 different model categories were examined (*Table 1*). Accordingly, the model class with the highest accuracy was determined as decision trees. The accuracy of decision trees varies between 82.5% and 85.1%. Decision trees are among the most widely used classification techniques (Aktürk et al., 2012; Alan, 2014; Altaş and Gülpınar, 2012; Edwards-Murphy et al., 2016; Kadirhanogulları et al., 2021; Kavzoğlu and Çölkesen, 2010; Waheed et al., 2006; Wu et al., 2009). Decision trees are used to predict targets by applying many tests during data analysis. Each test creates a branch of the decision tree, and these branches continue the tests to form new subsets. The rules formed as a result of these tests, which continue until the last leaf node, have an if-then structure and are frequently used with decision trees to identify the items that can be members of a cluster, to classify various results in different categories, to predict the future, and to select the useful ones among many different variables (Bounsaythip and Rinta-Runsala, 2001; Emel and Taşkın, 2005).

In the study, the accuracy share was taken into account in deciding on the use of decision trees and it was determined that the model with the highest accuracy was decision trees. In explaining the decision tree method, the most appropriate socio-economic data obtained from agricultural enterprises were selected and the variable set created is shown in *Table 2*. In the variable set where the symbol, type and classification criteria of each variable are shown, the data are classified as continuous and categorical. Classification was made according to the savings potential of enterprises and savings were divided into 3 classes in the data model. Accordingly, if the savings rate is less than 0, it is classified as "No Savings", if it is between 0-50, it is classified as "Low Savings" and if it is between 50-100, it is classified as "High Savings".

**Table 1. Accuracy Shares and Explanations of Models Available for Classification Analysis**

| Model Classification | Model                      | Share of Accuracy | Mean                                                                                                                                                                                                                                                         |
|----------------------|----------------------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tree                 | Fine Tree                  | %85.1             | Decision trees are the most widely used classification technique. This technique allows the data set to be divided into smaller clusters according to rules.                                                                                                 |
|                      | Medimum Tree               | %85.1             |                                                                                                                                                                                                                                                              |
|                      | Coarse Tree                | %82.5             |                                                                                                                                                                                                                                                              |
| Discriminant         | Linear Discriminant        | %60.8             | Discriminant analysis is the classification algorithm to try because it is fast, accurate and easy to interpret. Discriminant analysis is used for large datasets and assumes that different classes produce data based on different Gaussian distributions. |
| Naive Bayes          | Kernel Naive Bayes         | %66.8             | Bayes' theorem is used in this classification algorithm, which assumes that predictors are conditionally independent.                                                                                                                                        |
| SVM                  | Linear SVM                 | %75.0             | Support Vector Machines (SVM) classify data by finding the best hyperplane that separates data points of one class from data points of another class. For an SVM, the best hyperplane means the one with the largest margin between the two classes.         |
|                      | Quadratic SVM              | %79.5             |                                                                                                                                                                                                                                                              |
|                      | Qubic SVM                  | %78.7             |                                                                                                                                                                                                                                                              |
|                      | Fine Gaussian SVM          | %62.7             |                                                                                                                                                                                                                                                              |
|                      | Medium Gaussian SVM        | %75.4             |                                                                                                                                                                                                                                                              |
|                      | Coarse Gaussian SVM        | %62.7             |                                                                                                                                                                                                                                                              |
| KNN                  | Fine KNN                   | %58.6             | Nearest neighbor classifiers typically have good prediction accuracy in low dimensions but are not easy to interpret due to their high memory usage.                                                                                                         |
|                      | Medium KNN                 | %68.3             |                                                                                                                                                                                                                                                              |
|                      | Coarse KNN                 | %65.7             |                                                                                                                                                                                                                                                              |
|                      | Cosine KNN                 | %67.2             |                                                                                                                                                                                                                                                              |
|                      | Cubic KNN                  | %64.6             |                                                                                                                                                                                                                                                              |
|                      | Weighted KNN               | %67.9             |                                                                                                                                                                                                                                                              |
| Ensemble             | Boosted Trees              | %62.7             | Ensemble classifiers combine results from many weak learners into a single high-quality ensemble model. The qualities depend on the choice of algorithm.                                                                                                     |
|                      | Bagged Trees               | %84.7             |                                                                                                                                                                                                                                                              |
|                      | Subspace Discriminant      | %71.6             |                                                                                                                                                                                                                                                              |
|                      | Subspace KNN               | %79.9             |                                                                                                                                                                                                                                                              |
|                      | RUSBoosted Trees           | %76.9             |                                                                                                                                                                                                                                                              |
| Neural Network       | Narrow Neural Network      | %75.7             | Neural network models typically have good prediction accuracy and can be used for multi-class classification; however, they are not easy to interpret. Model flexibility increases with the size and number of fully connected layers in the neural network. |
|                      | Medium Neu. Net.           | %78.7             |                                                                                                                                                                                                                                                              |
|                      | Wide Neu. Net.             | %83.6             |                                                                                                                                                                                                                                                              |
|                      | Bilayered Neu. Net.        | %79.1             |                                                                                                                                                                                                                                                              |
|                      | Trilayered Neu. Net.       | %73.5             |                                                                                                                                                                                                                                                              |
| Kernel               | SVM Kernel                 | %79.5             | Kernel classification models are high-dimensional transformed predictive models using low-dimensional predictors.                                                                                                                                            |
|                      | Logistic Regression Kernel | %72.0             |                                                                                                                                                                                                                                                              |

**Table 2. Variable Set Used in the Classification Model**

| Variable Name                         | Type        | Classification                                                                                                                               |
|---------------------------------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Age                                   | Continuous  | Year                                                                                                                                         |
| Education                             | Categorical | 0: Illiterate, 1: Literate, 2: Primary school, 3: Secondary school, 4: High school, 5: University                                            |
| Number of Households                  | Categorical | Number of People                                                                                                                             |
| Experience                            | Continuous  | Year                                                                                                                                         |
| Social Security                       | Categorical | 0: None, 1: Social Insurance Institution, 2: Social Security Organization for Artisans and Self-Employed, 3: Pension Fund, 4: Green Card     |
| Land Size                             | Continuous  | Decare                                                                                                                                       |
| GDP                                   | Continuous  | US \$                                                                                                                                        |
| Gross Profit                          | Continuous  | US \$                                                                                                                                        |
| Disposable Agricultural Income        | Continuous  | US \$                                                                                                                                        |
| Non-Agricultural Income               | Continuous  | US \$                                                                                                                                        |
| Total Revenue                         | Continuous  | US \$                                                                                                                                        |
| Household Expenditures                | Continuous  | US \$                                                                                                                                        |
| Loan Utilization Amount               | Continuous  | US \$                                                                                                                                        |
| Support Amount                        | Continuous  | US \$                                                                                                                                        |
| TARSIM                                | Categorical | 1: No Insurance, 2: Insurance                                                                                                                |
| Contract Production                   | Categorical | 1: No Contracted Production, 2: Contracted Production                                                                                        |
| Number of Organization Members        | Continuous  | Quantity                                                                                                                                     |
| Health Status                         | Categorical | 1: Not good at all, 2: Not good, 3: Fair, 4: Good, 5: Very good                                                                              |
| Youth dependency ratio                | Continuous  | Percentage Rate                                                                                                                              |
| Elderly dependency ratio              | Continuous  | Percentage Rate                                                                                                                              |
| Farmer registration system            | Categorical | 1: Not registered with the FRS, 2: Registered with the FRS                                                                                   |
| Record Keeping                        | Categorical | 1: No Records, 2: Keeps Records                                                                                                              |
| Risk Perception                       | Categorical | 1: Does Not Take Risk, 2: Takes Risk                                                                                                         |
| Marketing Channels                    | Categorical | 1: Broker, 2: Trader, 3: Cooperative, 4: Processing Plant, 5: Export, 6: Retail, 7: Direct Sales, 8: Regional Marketing (Store, Hotel, etc.) |
| Sales Methods                         | Categorical | 1: Advance, 2: Term, 3: Mixed                                                                                                                |
| Sales Times                           | Categorical | 1: Immediately after harvest, 2: 1 month after harvest, 3: 3 months after harvest, 4: 6 months after harvest, 5: I use it in my own business |
| Social Assistance to Other Households | Continuous  | US \$                                                                                                                                        |

### 3. Results and Discussion

Agricultural enterprises calculate total income by calculating disposable agricultural and non-agricultural income from annual activity results, and then subtract consumption expenditures from this income to calculate savings amounts (Karaaslan et al., 2022; Kozera et al., 2016; Lidi et al., 2017; Strzelecka and Zawadzka, 2023; Zeng et al., 2023). Various theories test the obtained savings rates, concluding that the amount of savings varies with income. However, as is well known, countries or businesses are moving beyond traditional economic models and focusing on understanding the way people make economic decisions and their behavior. Traditional economics assumes that people are always rational, income-oriented, and perfectly informed. However, in real life, people's behavior does not conform to rational expectations and evolves in different ways depending on economic stability, social environment, cultural factors, and psychological thought patterns. Therefore, for a better understanding of saving behavior, it is necessary to examine it with a behavioral economics approach. This approach aims to explore the broader factors behind economic decisions by addressing people's emotional reactions, limited rationality, biases in decision-making processes, and behavioral patterns. As a result, it is unrealistic to consider only income and expenditures and measure saving behavior without considering other variables such as personal, financial, and environmental factors. Traditional economic behavior measures such a calculation, requiring integrated models to capture the complexity and unpredictability of people's decision-making in the real world. These models aim to adopt an approach that takes into account not only financial indicators, but also all indicators of behavioral, psychological, social, and environmental adaptation. For this reason, socio-economic and environmental criteria were utilized to determine the savings potential of agricultural enterprises, or, in other words, to reveal their real potential. With the help of the criteria determined, a classification model that takes into account all factors were used. The most widely used classification model in recent years has been artificial neural networks. This model classifies the data by utilizing the common features present in the data. The artificial neural network model

classifies the enterprises using all model variables against the existing data classification, thereby estimating their savings potential. To determine the savings potential of enterprises, 29 different models were tested in 9 model classes. The model class with the highest accuracy was determined as a decision tree. The accuracy of decision trees ranged from 82.5% to 85.1%.

Table 3 displays the descriptive statistics of the variables used in the model. According to the obtained data, the average age of the operators is 52 years old, the majority are primary school graduates, there are 3.73 households, and they have been engaged in agriculture for an average of 28 years. Their land size is 281 decars, their total income is \$56494.88, and their household expenditures are \$10908.74

**Table 3. Descriptive Statistics of the Model**

|                                       | Minimum  | Maximum    | Average     | Standard Deviation |
|---------------------------------------|----------|------------|-------------|--------------------|
| Age                                   | 18.00    | 77.00      | 51.8209     | 13.40              |
| Education                             | .00      | 4.00       | 1.7649      | .96                |
| Number of Households                  | 1.00     | 10.00      | 3.7388      | 1.85               |
| Experience                            | 3.00     | 60.00      | 28.7649     | 13.39              |
| Social Security                       | .00      | 3.00       | 1.3582      | .55                |
| Land Size                             | .00      | 4.200.00   | 281.6604    | 354.02             |
| GDP                                   | 5.610.23 | 720.494.93 | 93.808.86   | 107.082.62         |
| Gross Profit                          | 5.972.32 | 530.322.04 | 64.375.24   | 85.721.92          |
| Disposable Agricultural Income        | 9.303.82 | 516.498.65 | 5.3715.58   | 75.668.55          |
| Non-Agricultural Income               | 0        | 58.605.17  | 2.779.30    | 5.293.95           |
| Total Income                          | 2.631.60 | 530.756.24 | 56.494.88   | 76.018.04          |
| Household Expenditures                | 1.198.65 | 30.642.51  | 10.908.74   | 6.575.23           |
| Loan Utilization Amount               | 0        | 337.457.81 | 19.402.98   | 3.6315.79          |
| Support Amount                        | 0        | 158.098.98 | 4.049.37    | 14.522.08          |
| TARSIM                                | .00      | 2.00       | 1.7500      | .44                |
| Contract Production                   | 1.00     | 3.00       | 1.7388      | .45                |
| Number of Organization Members        | 1.00     | 5.00       | 2.6119      | 1.41               |
| Health Status                         | 1.00     | 5.00       | 3.4552      | 1.43               |
| Youth dependency ratio                | .00      | 50.00      | 7.4142      | 11.67              |
| Elderly dependency ratio              | .00      | 200.00     | 15.6604     | 25.90              |
| Farmer registration system            | 1.00     | 2.00       | 1.0970      | .29                |
| Record Keeping                        | 1.00     | 2.00       | 1.7537      | .43                |
| Risk Perception                       | 1.00     | 5.00       | 3.2873      | .82                |
| Marketing Channels                    | 1.00     | 8.00       | 2.4440      | 1.12               |
| Sales Methods                         | 1.00     | 3.00       | 1.2537      | .59                |
| Sales Times                           | 1.00     | 4.00       | 1.2910      | .57                |
| Social Assistance to Other Households | .00      | 41.7257.00 | 34.792.3507 | 57.291.38          |

As a result of the classification analysis. it is known that 62.69% (168 enterprises) of the enterprises have high savings. 32.84% (88 enterprises) have low savings and 4.48% (12 enterprises) cannot save in the data model obtained from the available financial data (*Figure 1*). These data were obtained by subtracting total expenditures from total income. However. many studies have shown that there are many effective factors in the formation of savings in agricultural enterprises (Kozera et al., 2016; Mapesa, 2015; Nayak, 2013; Suresh et al., 2019) and in this context. the study tried to determine how effective many social. environmental and financial factors are in the formation of real savings potentials.



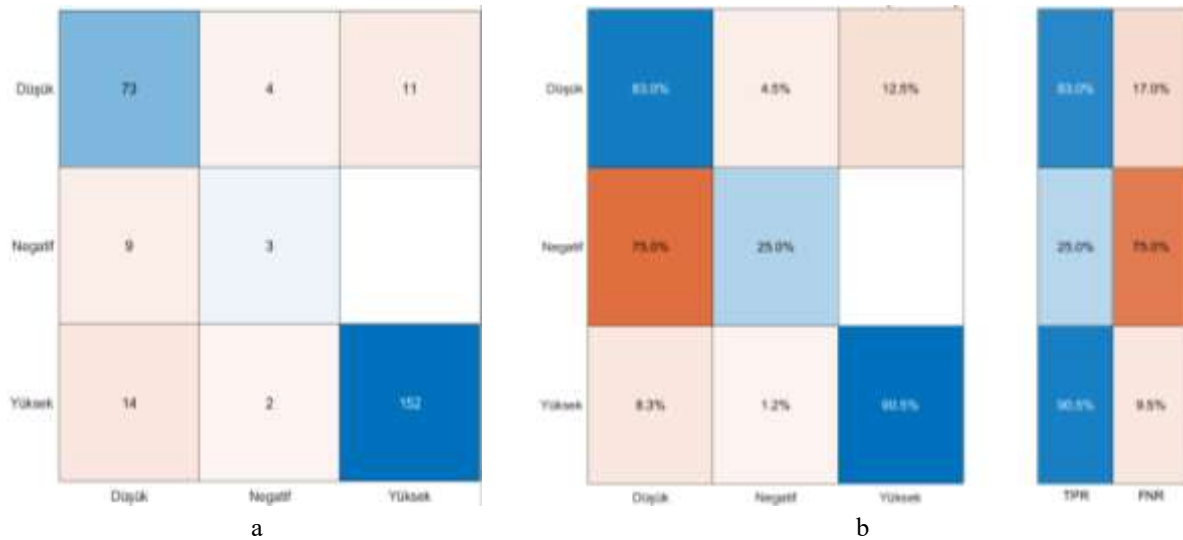


**Figure 1. Data Model Estimation (a) and Classification of Saving Potentials (b)**

As a result of the modeling, 83% of the enterprises identified as low savings in the data model were correctly predicted. Of the 17% that were not predicted correctly, 4.5% do not save at all, while 12.5% have high savings potential. In the model, 75% of the enterprises with no savings were correctly estimated and 25% were incorrectly estimated. All the incorrect estimates were identified as enterprises with low saving tendency. Finally, because of the calculations, 90.5% of the enterprises classified as high savings were correctly estimated, while 9.5% were incorrectly estimated. Of those that were incorrectly estimated, 8.3% were low saving enterprises and 1.2% were enterprises with no savings at all. As a result of the evaluations made accordingly, it is seen that socio-economic factors have a significant effect on the formation of savings potentials. It is seen that enterprises with low savings have high savings potential or enterprises with high savings have low savings potential. Accordingly, it can be said that enterprises with low savings cannot use their real potential and the resources they have effectively and efficiently. It can be said that they can increase the amount of savings thanks to their knowledge and skills. Similarly, 25% of the enterprises with no savings are expected to have low savings, but it is seen that they cannot use their real potential. It can be said that external factors have an impact on the group that has high potential but is expected to have low savings. Climate, topographical structure, location of the enterprise and the high level of entrepreneurial ability, which is an endogenous factor, can be said to have a high level of savings because of these factors.

**Table 4. Comparison of Data and Forecasting Models According to Enterprise Size Groups**

| Enterprise Sizes                |                 | 0-50     | 51-150   | 151-500   | 501+       | Average   |
|---------------------------------|-----------------|----------|----------|-----------|------------|-----------|
| Total Revenue (\$)              |                 | 4.991,16 | 7.673,48 | 23.760,14 | 107.221,52 | 18.643,40 |
| Household Consumption Exp. (\$) |                 | 4.878,31 | 6.900,83 | 11.364,15 | 21.211,62  | 10.621,60 |
| Savings Amount (\$)             |                 | 112.84   | 772.65   | 12.395,99 | 86.009,90  | 8.021,79  |
| Savings Ratio                   |                 | 2.26     | 10.07    | 52.17     | 80.22      | 43.03     |
| Low Saving Enterprises.         | Data Mod.       | 33.33    | 42.31    | 31.72     | 11.11      | 39.80     |
|                                 | Estimation Mod. | 50.00    | 46.15    | 32.41     | 11.11      | 34.70     |
| High Saving Enterprises.        | Data Mod.       | 55.56    | 46.15    | 68.28     | 85.19      | 55.22     |
|                                 | Estimation Mod. | 44.44    | 44.87    | 66.90     | 85.19      | 53.36     |
| Negative Saving Enterprises.    | Data Mod.       | 11.11    | 11.54    | 0.00      | 3.70       | 12.69     |
|                                 | Estimation Mod. | 5.56     | 8.97     | 0.69      | 3.70       | 11.94     |

Table 4 shows the comparison of data and estimation models according to enterprise size groups. Accordingly, while the amount of savings in enterprises with a land size between 0-50 decare was 112.84 dollar, the savings rate was determined as 2.26%. While this rate was 10.07% in enterprises with 51-150 decare, it was 52.17% in enterprises with 151-500 decare and 80.22% in enterprises with 501 and more land. Therefore, according to the

average of enterprises. the saving rate of agricultural enterprises in Konya province was determined as 43.03%. In this direction. data model and estimation models were compared according to enterprise size groups. The enterprise group with high saving rates was determined as enterprises with a land size of 501 and above in both data and estimation models. In addition. it is seen that the rate of enterprises with negative and low savings decreases as the size of the enterprise increases.

**Table 5. Structural. Social and Economic Characteristics of Enterprises by Savings Structure**

| Indicators                            | Negative Saving | Low Saving | High Saving |
|---------------------------------------|-----------------|------------|-------------|
| Age                                   | 47.18           | 52.72      | 54.60       |
| Education                             | 2.00            | 2.23       | 2.77        |
| Number of Households                  | 3.27            | 3.17       | 3.09        |
| Experience                            | 24.73           | 26.85      | 28.99       |
| Social Security                       | 1.27            | 1.40       | 1.34        |
| Land Size                             | 128.09          | 181.43     | 346.45      |
| GDP                                   | 26.803,82       | 37.811,36  | 130.623,70  |
| Gross Profit                          | 7.500,66        | 17.361,95  | 95.325,37   |
| Disposable Agricultural Income        | 5.439,94        | 11.721,70  | 81.190,79   |
| Non-Agricultural Income               | 2.302,18        | 3.164,45   | 2.589,38    |
| Total Revenue                         | 7.742,14        | 14.886,15  | 83.780,17   |
| Household Expenditures                | 2.817,59        | 3.013,60   | 2.873,53    |
| Loan Utilization Amount               | 6.544,63        | 15.249,62  | 22.665,92   |
| Support Amount                        | 139.13          | 95.26      | 159.93      |
| TARSIM                                | 1.64            | 1.48       | 1.34        |
| Contract Production                   | 1.32            | 1.48       | 1.71        |
| Number of Organization Members        | 2.51            | 2.63       | 3.27        |
| Health Status                         | 3.13            | 3.48       | 3.82        |
| Youth dependency ratio                | 9.82            | 7.46       | 7.23        |
| Elderly dependency ratio              | 5.45            | 16.16      | 16.06       |
| Farmer registration system            | 1.18            | 1.27       | 1.40        |
| Record Keeping                        | 1.33            | 1.58       | 1.74        |
| Risk Perception                       | 3.07            | 3.27       | 3.30        |
| Marketing Channels                    | 2.27            | 2.53       | 2.70        |
| Sales Methods                         | 1.36            | 1.22       | 1.16        |
| Sales Times                           | 1.27            | 1.35       | 1.66        |
| Social Assistance to Other Households | 837.28          | 1.848,28   | 5.312,32    |

Table 5 compares the structural. social and economic characteristics of agricultural enterprises according to their savings structure. This comparison was prepared in line with the data obtained according to the saving prediction models of the enterprises. Accordingly. when the characteristics of the enterprises according to their savings structure are analyzed. it can be said that the enterprises with negative savings are managed by young operators and have low education levels and land sizes. In addition. while their income is lower than other enterprises. their per capita household expenditures are lower. It can be said that institutional skills such as contracted production. agricultural insurance and membership to organizations are weak in this group of enterprises. which are seen to be inadequate in the use of financial resources. Enterprises with low savings show higher economic and social adaptation flexibility than enterprises with negative savings. These enterprises show higher resilience against possible risks than the enterprises in the first group. However. their sustainability is likely to be jeopardized in case of a crisis. High-savings enterprises. on the other hand. are characterized by the presence of highly educated managers. effective cost management. high profitability and efficient supply chains. while having more experienced managers than other enterprises. High-savings businesses are those that manage costs effectively and develop strategies to increase revenues. These enterprises balance the production and supply process by carefully evaluating their investments and projects through cost-performance analysis. At the same time. they show high sensitivity to potential risks by using technology effectively and implementing risk strategies. They continuously develop their workforce by emphasizing the training and development of households. They focus on income-enhancing strategies and are careful in debt management. They avoid the accumulation of idle

stocks by effectively managing idle labor and capital with rational resources. All these characteristics help high-saving enterprises to achieve sustainable success and gain competitive advantage.

#### 4. Conclusions

The use of savings in agricultural enterprises is critical for financial security and sustainable development. Agribusinesses save money by finding a balance between income levels and costs. Increasing agricultural incomes, controlling expenses, and efficiently using resources enable agribusinesses to achieve savings. These savings provide financial security against emergencies and build strong resilience to fluctuations in agricultural activities. Simultaneously, savings fuel long-term objectives like enhancing household members' education and health, as well as modernizing agribusinesses. Therefore, we should analyze the savings potential of agricultural enterprises to ensure a more stable development of rural areas.

The studies conducted so far have evaluated the enterprises' savings potential based on the data obtained from the activity results. However, we should evaluate agricultural enterprises alongside households, incorporating all personal, environmental, and economic factors to uncover the true potential of the operators. According to the data model, 62.69% of the enterprises had high savings, but the estimation model determined this value to be 60.8%. Additionally, the estimation model determined the rate of enterprises with low savings from 32.84% in the data model to 35.8%, while the data model found the rate of negative enterprises to be 4.48% in the data model and 3.4% in the estimation model. The study also compared the data and estimation models based on enterprise size groups. Accordingly, the difference between the data and prediction models was high in small-scale agricultural enterprises, but the deviations between the models decreased as the enterprise scale increased. Especially in the fourth group of agricultural holdings, no deviation was observed. This provides another indication of enterprise record consistency. As a matter of fact, as the scale of the enterprise increases, it is easier to measure the real potential of the enterprise with increasing specialization and registration.

In the study, after determining the savings potential of agricultural enterprises, the structural, social, and economic characteristics of the enterprises were clustered according to their savings structures. As a matter of fact, structures and patterns in the data sets were discovered by bringing together data points with similar characteristics in agricultural enterprises shown in three clusters. The evaluations provided information such as the demographic, structural, production, and marketing strategies of the enterprises, which contributed to the improvement of the decision-making process. As a result, ways to increase savings in agricultural enterprises are important in terms of ensuring economic security, conducting sustainable agricultural activities, and making investments for the future. Agricultural enterprises should utilize alternative income models for this purpose. Increasing productivity, growing quality products, and improving marketing strategies will contribute to achieving higher savings. At the same time, by joining agricultural cooperatives and marketing associations, they can increase their savings by taking advantage of collective marketing. Second, keeping costs under control is important. Steps such as waste management, efficient energy and water use, and optimizing input costs help to reduce expenses. Furthermore, reducing fuel and maintenance costs and avoiding idle expenditures through the effective use of agricultural technologies will also be effective in achieving savings. Third, agribusinesses can use savings to make future investments. Investing in education and skilled labor can increase the productivity of agribusinesses, while investing in modern agricultural equipment improves production processes and reduces costs.

As a result, the ways in which agribusinesses can increase savings focus on increasing income, keeping expenses under control, and investing for the future. Strategies such as using efficient farming techniques, joining agricultural cooperatives and marketing associations, reducing energy and input costs, using farm machinery effectively, and investing in renewable energy sources help agricultural households increase their economic security and sustainability. Savings for future-oriented investments are critical for modernizing agribusinesses and increasing their competitiveness. All these steps enable agricultural households to have a stronger and more sustainable financial structure and contribute to the economic development of rural areas.

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### **Ethical Statement**

This study was prepared under the permission numbered E.85699. dated 17/06/2021. from the Ethics Committee of Selcuk University." One of the phrases must be used.

### **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

### **Authorship Contribution Statement**

Concept: Ağızan, K., Bayramoğlu, Z.; Design: Karakayacı, Z., Ağızan, K.; Data Collection or Processing: Ağızan, K.; Statistical Analyses: Doğan, H. G.; Literature Search: Çelik, Y., Karakayacı, Z.; Writing. Review and Editing: Ağızan, K., Bayramoğlu, Z.

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**Yağlı Tohum Üretim Potansiyelinin Coğrafi Bilgi Sistemleri Kullanılarak Belirlenmesi:  
Balıkesir İli Örneği**

Determination of Oilseed Production Potential Using Geographic Information Systems: The  
Case of Balıkesir Province

Ömer Faruk KARACA<sup>1\*</sup>, Murat ERTUĞRUL<sup>2</sup>, Tanzer ERYILMAZ<sup>3</sup>

**Özet**

Dünyada ve ülkemizde yağlı tohumlu bitkiler stratejik ürün olarak kabul edilmektedir. Bu kaynaklardan biri olan yağlı tohumlu bitkilerin, gıda sektörü dışında biyodizel ve endüstriyel alanlarda kullanımı bitkisel yağlara talebi tüm dünyada artırmıştır. Bu çalışmanın amacı Dünya ve Türkiye’deki üretim verilerinin yardımıyla Balıkesir ilinin yağlı tohum üretim potansiyelinin son zamanlarda yaygın olarak kullanılan Coğrafi Bilgi Sistemleri (CBS) yardımıyla ortaya konulmasıdır. Bu amaçla öncelikle Dünya ve Türkiye’deki genel durum ortaya konulmuş ve daha sonra il ve ilçe ölçeğinde değerlendirilmiştir. Dünya ölçeğindeki veriler FAOSTAT, Türkiye verileri ise TÜİK’ten temin edilmiştir. Tüm veriler sırasıyla hasat edilen alan, üretim ve verim miktarlarına göre CBS yazılımına aktararak yıllara göre ve il ölçeğinde 5-10 sınıf arasında, ildeki mevcut verilerin miktarına göre yoğunluk değişim haritaları oluşturulmuştur. Düşük ve yüksek verime sahip mevcut alanlar belirlenerek sonraki yıllarda o bölgelerde yapılabilecek üretim politikaları ve planlamaları için altlık oluşturulması hedeflenmiştir. Dünya’da yağlı tohumlu bitkilerde hasat edilen alana göre tarımı en çok yapılan ürünler arasında soya ilk sırada yer almaktadır. Soya bitkisinin tarımı en çok yapılan ülkeler ise sırasıyla Brezilya (40.894.968 ha), ABD (34.939.320 ha), Arjantin (158.742.66 ha), Hindistan (121.465.80 ha) ve Çin (10.243.000 ha)’dır. Soyadan sonra sırasıyla kanola, pamuk, ayçiçeği, aspir, susam ve haşhaş gelmektedir. Türkiye’de toplamda ürünlerin yetiştirildiği il sayıları bakımında ise ilk sırada ayçiçeği (59 il), ikinci sırada aspir (42 il), üçüncü sırada ise (32 il) susam gelmektedir. Alansal olarak ilk sırada ayçiçeği (3.618.226 ha), ikinci sırada yerfıstığı (176.733 ha), üçüncü sırada ise pamuk (1.659.601 ha) yer almaktadır. Toplamda 385.095.8 ha tarım alanına sahip Balıkesir ilinde 283.416 dekarlık bir alanda (%7.5) yağlı tohum bitki üretimi yapılmaktadır. İlde ilk sırada ayçiçeği, ikinci sırada susam ve üçüncü sırada kanola veya kolza tarımının yapıldığı tespit edilmiştir.

**Anahtar Kelimeler:** Yağlı tohumlu bitkiler, Biyodizel, Balıkesir, CBS, Alternatif enerji

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## Abstract

Oilseed crops are considered strategic products in the world and in our country. The use of oilseed crops, one of these resources, in biodiesel and industrial areas other than the food sector has increased the demand for vegetable oils all over the world. The aim of this study is to reveal the oilseed production potential of Balıkesir province with the help of production data in the world and Turkey, with the help of Geographic Information Systems (GIS), which has been widely used recently. For this purpose, the general situation in the world and Turkey was first presented and then evaluated at the provincial and district scale. Data on the world scale were obtained from FAO, and data on Turkey were obtained from TÜİK. All data were transferred to the GIS software according to the harvested area, production and yield amounts, and density change maps were created according to the amount of data available in the province, between 5-10 classes on the provincial scale, according to the years. It was aimed to determine the existing areas with low and high yields and to create a basis for production policies and plans that can be made in those regions in the following years. Soybean ranks first among the products most cultivated in terms of harvested area among oilseed crops in the world. The countries where soybean is cultivated the most are Brazil (40.894.968 ha), USA (34.939.320 ha), Argentina (158.742.66 ha), India (121.465.80 ha) and China (10.243.000 ha). After soybean, canola, cotton, sunflower, safflower, sesame and poppy come first. In terms of the total number of provinces where products are cultivated in Turkey, sunflower (59 provinces) comes first, safflower (42 provinces) comes second and sesame (32 provinces) comes third. In terms of area, sunflower (3.618.226 ha) comes first, peanut (176.733 ha) comes second and cotton (1.659.601 ha) comes third. In Balıkesir province, which has a total agricultural area of 3.850.958 da, oilseed plant production is carried out in an area of 283.416 decares (7.5%). It has been determined that sunflower is the first crop in the province, sesame is the second and canola or rapeseed is the third.

**Keywords:** Oilseed plants, Biodiesel, Balıkesir, GIS, Alternative energy

## 1. Giriş

Dünyada ve ülkemizde yağlı tohumlu bitkiler stratejik ürün olarak kabul edilmektedir (Uğur, 2012). Yağlı tohumlu bitkiler tohumlarında içerdikleri yağ ile bitkisel yağ sanayine, yağ alındıktan sonra kalan küspeleri ile yem sanayine hammadde sağlamaktadırlar. 2022 yılında toplam 2.7129.648 ton karma yem üretildiği göz önüne alındığında, yağlı tohumlu bitkilerin dünya tarımı bakımından ne derece önemli olduğu ortaya çıkmaktadır (TUYEKAD, 2024). Ayrıca son yıllarda fosil yakıtların çevreye olan olumsuz etkileri ve sınırlı kaynak olmaları, yenilenebilir enerji kaynaklarının kullanımını gündeme getirmiştir. Bu kaynaklardan biri olan yağlı tohumlu bitkilerin, gıda sektörü dışında biyodizel ve endüstriyel alanlarda kullanımı bitkisel yağlara talebi tüm dünyada artırmıştır (Bayramin, 2006).

Doymuş yağ asidi miktarının hayvansal kaynaklı olan yağlara nazaran daha düşük olması sebebiyle bitkisel yağların insan beslenmesinde oldukça büyük önemi vardır. Doymuş yağ asidi yüzdesi yağ türleri itibarıyla, ayçiçeği yağında %11, soya yağında %15, mısır özü yağında %13, kolza yağında %6, zeytinyağında %14, tereyağında ise %66'dır. Ülkemizde bulunan bitkisel yağ tüketimi ise kişi başına 17 kilogram olup, sağlıklı olan bir beslenme için bunun 24 kilograama kadar yükseltilmesi gerekir. Bunun için bitkisel yağ imalatının artırılması zorunludur (Anonim, 2024a).

Türkiye soya üretimi açısından dünyada önemli bir potansiyele sahip olmamakla birlikte, birim alandan alınan verimde dünyada ilk sıralarda gelmektedir. Soya, Türkiye'de hem ana ürün hem de ikinci ürün olarak yetiştirilebilme imkânına sahip bir ürün olarak dikkat çekmektedir. Soya tohumları içerdiği yüksek orandaki yağ, protein, karbonhidrat, vitaminler ve madensel maddeler ile insanlar ve hayvanlar için değerli bir besin kaynağıdır. Soya tohumları %18-24 oranında yağ, %35-40 dolayında protein içermekte ve toprağa organik madde ve azot sağlamaktadır. Aynı zamanda soyanın en çok bilinen ve en çok kullanılan ürünleri yine soya yağı ve soya küspesidir. Soya yağı dünyada palm yağından sonra en yaygın kullanılan yemeklik yağ, soya unu ise hayvan yemi için başlıca protein ve enerji kaynağıdır. Soya ayrıca ekmek, salata sosu, kahve kreması gibi gıda ürünlerinin yanında temizlik malzemeleri, kozmetik sektörü, plastik gibi sanayi sektöründe de birçok kullanım alanına sahiptir (Anonim, 2024b).

Susam tarımının el emeğine dayalı bir şekilde yürütülmesi ve verimin az olması, yağ bakımından değerlendirildiğinde imalat maliyetlerinin yükselmesine sebep olmaktadır. Bu da diğer bitkisel yağlar ile rekabet edememesi neticesini meydana getirmektedir. Helva ve tahin imalatında kullanılan susam taneleri %50-60 yağ, %25 protein bulundurulur. Yağın kalitesi yüksek olup hoş kokulu ve dayanıklıdır. Ayrıca cilt bakım ürünlerinde de tercih edilmektedir (Tan, 2015).

Dünya bitkisel yağ imalatında kullanılan yaklaşık olarak 8 yağ bitkisinden ilk üçü arasında bulunan yer fıstığı, baklagiller ailesinden, tek senelik ve yazlık olan bir bitkidir. Bileşimde %45-55 yağ, %20-25 protein, %16-18 karbonhidrat, %25 mineral madde yer almaktadır. Hafif bünyeli, kumlu ve tınlı olan topraklarda büyüme zamanı boyunca 4-8 kere sulanan yer fıstığı mayıs ve haziran aylarında hasadı yapılan ürünlerden sonra 2. ürün şeklinde ekilebilir. Yer fıstığı yağı, özellikle Asya mutfağında yaygın olarak kullanılmaktadır (Kadiroğlu, 2023).

Ayçiçeği tohumlarından elde edilen yağ, yüksek oranda doymamış yağ asitleri içermektedir. Ayçiçeği yağı, kızartmalardan hamur işlerine kadar geniş bir yelpazede kullanılmaktadır (Meral, 2019). Pamuk bitkisinin tohumlarından elde edilen pamuk yağı, tekstil endüstrisinde kullanılırken, çiğit yağı da yemeklik yağ olarak tüketilmektedir. Kanola bitkisinin tohumlarından elde edilen yağ, düşük doymuş yağ içeriğiyle sağlıklı bir seçenektir. Kanola yağı, yemek pişirmeden margarin üretimine kadar birçok alanda kullanılmaktadır. Keten tohumlarından elde edilen keten yağı, omega-3 yağ asitleri bakımından zengindir. (Anonim, 2024b).

Haşhaş (*Papaver somniferum* L.) Papaveraceae familyasına ait alkaloitlerce zengin değerli bir ilaç ve keyf bitkisidir (Rahimi ve ark., 2011; Baydar 2009). Dünyada 22 tür ile temsil edilen haşhaşın, Türkiye'de 15'i endemik olmak üzere 58 taksonu bulunmaktadır (Davis, 1988; Güner ve ark., 2012; USDA, 2024). Osmanlı İmparatorluğu zamanında da gelir getirici bir bitki olarak önemini korumuştur. Ancak, haşhaş uyuşturucu özelliğinden dolayı, 1933 yılından beri ülkemizde yetiştiriciliği bazı kurallara göre yapılmaktadır. 1938 yılında Toprak Mahsulleri Ofisi (TMO)'nin kurulmasıyla beraber temini ve tarımı devlet gözetiminde yapılmaya başlanmıştır (Gümüştü, 1996). Başta morfin olmak üzere içerdiği alkaloidlerinin birçoğunun uyuşturucu özelliği nedeniyle ilaç sanayisinde kullanılmasından dolayı, haşhaş tohumu ekiliş alanları diğer yağlı tohumlu bitkilere nazaran daha alt seviyelerde kalabilmektedir (Kolsarıcı, 2006).

Aspir, suya gereksinim duymadan kurak, çorak ve verimi düşük olan arazilerde yetiştirilebilmesi, bakım gerektirmemesi, yabani hayvanların zarar vermemesi ve adaptasyon sınırlarının geniş olması nedeniyle sebebiyle ülkemizin hemen her bölgesinde rahatlıkla yetiştirilebilen alternatif bir yağ bitkisidir (Öğüt ve ark., 2007). Kurak, çorak ve yabani hayvanların zarar verdiği arazilerde buğday verimi düşeceğinden aspir ekimi daha kazançlı olacaktır. Yapılan bilimsel çalışmalarda aspir bitkisinin tohumlarının satılması yerine biyodizel üretildiğinde daha fazla kazanç elde edildiği ve kanoladan daha verimli olduğu

görülmüştür (Yılmaz ve ark., 2015). Ayrıca köklerinin toprağın derin katmanlarına inebilmesi ile toprağın farklı katmanlarındaki su ve besin maddelerinden yararlanabilmesi, dikenli ve dikensiz çeşitlerinin oluşu, kurağa ve sıcağa toleranslı olması aspir bitkisinin ülkemiz tarımı için önemini arttırmaktadır (Bayramın ve Kaya, 2009). Tohumlarında bulunan %35-40 oranındaki yağ doymuş yağ asitleri yüzdesinin düşük, doymamış yağ asitleri yüzdesinin yüksek olması nedeniyle kaliteli bir yağdır (Berglund ve ark., 1998). Aspir bitkisinin tohumlarından elde edilen aspir yağı, boya ve vernik üretiminde kullanılmaktadır.

Kolza (*Brassica napus* ssp. *oleifera*) Cruciferae familyasından, yazlık ve kışlık olarak ekilebilen tek yıllık bir yağ bitkidir. Tohumlarında %40-45 yağ ve küspesinde %37 protein içermektedir. Bitkisel yağ elde edilmek amacıyla yetiştirilen kolza çeşitlerinde yağdaki erusik asit oranı %2'nin, küspedeki glikosinolat oranı 30µmol/gramın altındadır (Raymer, 2002). Yenilenebilir enerji kaynaklarının kullanımının yoğunlaştığı günümüzde, dizele alternatif biyodizelin üretilmesinde dünyada en fazla kolza yağı kullanılmaktadır. Dünyada üretilen biyodizelin %84'ü kolza yağından elde edilmektedir (Acar ve Gizlenci, 2021).

Bir bölgede tarımsal politika geliştirilmesi için öncelikle bölgenin mevcut durumu ve potansiyelinin belirlenmesi gerekmektedir. Bu amaçla kullanılan tarımsal üretim verilerinin eldesinden sonra hızlı bir şekilde işlenerek analizlerinin yapılması son derece önemlidir. CBS, bu analiz ve yorumlama işlemlerinin oldukça hızlandıran bir yöntemdir ve birçok alanda yoğun bir biçimde kullanılmaktadır. Uzaktan algılama teknolojilerindeki ilerlemeler ve mikrobilgisayar sistemlerinin çok hızlı gelişmesi bu teknolojilerin çok geniş uygulama alanları ve kullanıcılar için hazır ve göreceli olarak ucuz elde edilebilmesini sağlamıştır. Ülkemizde ise CBS ile ilgili çalışmalar 1980'li yıllarda başlamıştır. Günümüzde ise yaygın olarak birçok alanda kullanılmaktadır (Gürkan ve ark., 2016).

Bu çalışmanın amacı Dünya ve Türkiye'deki üretim verilerinin yardımıyla Balıkesir ilinin yağlı tohum üretim potansiyelinin son zamanlarda yaygın olarak kullanılan Coğrafi Bilgi Sistemleri (CBS) yardımıyla ortaya konulmasıdır. Bu amaçla öncelikle Dünya ve Türkiye'deki genel durum ortaya konulmuş ve daha sonra İl ve İlçe ölçeğinde değerlendirilmiştir. Dünya ölçeğindeki veriler (FAO, 2024), Türkiye verileri ise (TÜİK, 2024a)'dan temin edilmiştir. Tüm veriler sırasıyla hasat edilen alan, üretim ve verim miktarlarına göre CBS yazılımına aktararak yıllara göre ve il ölçeğinde 5-10 sınıf arasında, ildeki mevcut verilerin miktarına göre yoğunluk değişim haritaları oluşturulmuştur. Düşük ve yüksek verime sahip mevcut alanlar belirlenerek sonraki yıllarda o bölgelerde yapılabilecek üretim politikaları ve planlamaları için altlık oluşturulması hedeflenmiştir. Bu sayede karar vericiler ve çiftçiler açısından sorunlu veya sorun oluşturabilecek alanların önceden tespit edilmesi sağlanmış olacaktır.

## 2. Materyal ve Metot

Çalışma alanı olarak yağlı tohumların büyük bir çoğunluğunun yoğun olarak üretildiği Balıkesir ve ilçeleri seçilmiştir. Dünya ve Türkiye'deki genel durumun ortaya konulması için Dünya ile ilgili sayısal veriler FAO (2024), il ve ilçeye ait veriler ise TÜİK (2024a)'den il ve ilçe düzeyinde elde edilmiştir. Uzaktan algılama ile ilgili herhangi bir uydu verisi kullanılmamıştır. Bunun yerine CBS yazılımlarından olan ArcGIS v10.8 ile elde edilen sayısal veriler üzerinden yoğunluk ve mekânsal analizler yapılmıştır. Bu analizlerde sayısal veri aralığına sahip bölgelere göre farklı değerler atanarak yoğun veya sorunlu alanlar daha hızlı bir şekilde belirlenmeye çalışılmıştır. Altlık olarak kullanılan ve il sınırını belirleyen .shp uzantılı sayısal vektör haritaları, Harita Genel Müdürlüğü (HGM, 2024)'den temin edilmiştir.

### 2.1. Materyal

#### Balıkesir ili genel özellikleri

Balıkesir İli, Anadolu Yarımadası'nın kuzeybatısında ve önemli bir bölümü Marmara coğrafi bölgesinin, Güney Marmara bölümünün, Karesi yöresinde; diğer küçük bir bölümü ise, Ege coğrafi bölgesindeki Asıl Ege bölümünün Kuzey Ege kesiminde yer alır (*Şekil 1*). İlin izdüşüm yüzölçümü 14456 km<sup>2</sup>, olup 39 06" ve 40 39" kuzey enlemleri ile, 26 39" ve 28 58" doğu boylamları arasında yer almaktadır. Balıkesir ili genellikle tepelerin hâkim olduğu bir alan niteliği taşımakla birlikte yer yer 1800 metreyi bulan dağların yer aldığı görülür. Genelde yarı nemli iklim koşulları altında mikaşist, gnays, fillat ve kristalize kireçtaşı gibi anakayalar üzerinde gelişen topraklar kahverengi orman topraklarıdır. Yıllık ortalama sıcaklıklar Edremit 16.2 °C, Bandırma 14.1 °C, Balıkesir 14.5 °C, Dursunbey 12.1 °C olarak ölçülmektedir. Merkeze yılda ortalama 588.5 mm yağış düşmektedir (Anonim, 2024c).

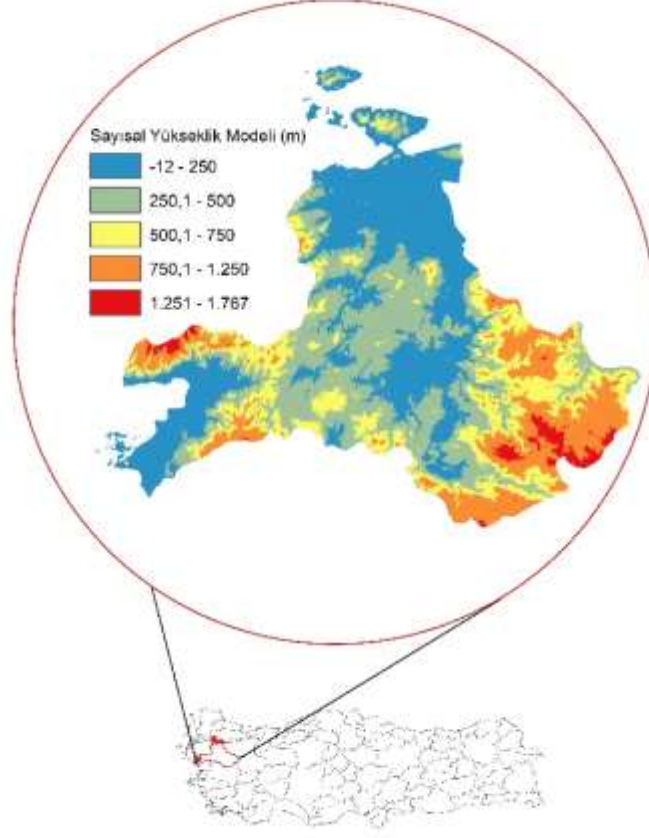


Figure 1. Location of work area

Şekil 1. Çalışma alanı konumu

## 2.2. Yöntem

Tüm veriler excel yazılımı ile düzenlenmiştir. İstatistiki hesaplamalar ve düzenlemeler SPSS v21 paket programı aracılığıyla yapılmıştır. Düzenlenen veriler ülke ve il isim sıraları ölçüt alınarak join (birleştir) işlemi ile ArcGIS'a aktarılmıştır. Verisi olmayan ülke veya il değerlerine, program işlem koşulu nedeniyle sıfır atanmıştır. İl ve ilçe sınırlarını belirleyen .shp uzantılı altlık haritaları yazılıma aktarıldıktan sonra, bulunma sıklığına göre veriler düzenlenerek symbology (sembolleştirme) özelliğindeki kategoriye ayırma araç çubuğu ile yoğunluk haritaları oluşturulmuştur. Her bir veri seti ayrı ayrı 3-10 class aralığında olacak şekilde düzenlenmiştir. Lejant değerleri oluşturulurken bu class aralıkları aynen kullanılmıştır.

## 3. Araştırma Sonuçları ve Tartışma

### 3.1. Dünya'da yağlı bitkilerin genel durumu

Dünya'da yağlı tohumlu bitkilerde hasat edilen alana göre tarımı en çok yapılan ürünler arasında soya ilk sırada yer almaktadır. Soya bitkisinde hasat edilen alan bakımında tarımı en çok yapılan ülkeler ise sırasıyla Brezilya (40.894.968 ha), ABD (34.939.320 ha), Arjantin (15.874.266 ha), Hindistan (1.214.658 ha) ve Çin (10.243.000 ha)'dir. Soyadan sonra sırasıyla kanola, pamuk, ayçiçeği, aspir, susam ve haşhaş gelmektedir. Kanola Kanada (8.596.300 ha), Pamuk Hindistan (1.2371.520 ha), Ayçiçeği Rusya Federasyonu (9.182.873 ha), Aspir Kazakistan (633.441 ha), Susam Sudan (4.151.896 ha) ve Haşhaş ise Türkiye'de (26.501 ha) en çok üretilen yağlı tohumlu bitkiler arasında ilk sırayı almaktadır (FAO, 2024) (Şekil 2) (Tablo 1).

Üretim miktarlarına (ton) bakıldığında benzer şekilde soya üretimi yine ilk sırada yer almaktadır (Tablo 1). Soyadan sonra sırasıyla kanola, pamuk, ayçiçeği, susam, aspir ve haşhaş gelmektedir. Burada üretim alanlarından farklı olarak susam üretimi aspir üretiminden bir miktar daha fazla olmuştur. Üretim miktarlarına göre en fazla ürünün elde edildiği ülkeler soya Brezilya (120.701.031 ton), kanola Kanada (18.694.768 ton), pamuk Çin (18.121.818 ton), ayçiçeği Rusya Federasyonu (16.362.215 ton), susam Sudan (1.231.701 ton), aspir Kazakistan (447.457 ton) ve haşhaş Türkiye (12.240 ton)'dir. Hindistan'da pamuk bitkisinin hasat edilen alan miktarı Çin'e oranla daha fazla olmasına rağmen Çin, elde ettiği ürün bakımından Hindistan'ın önüne geçmiştir.



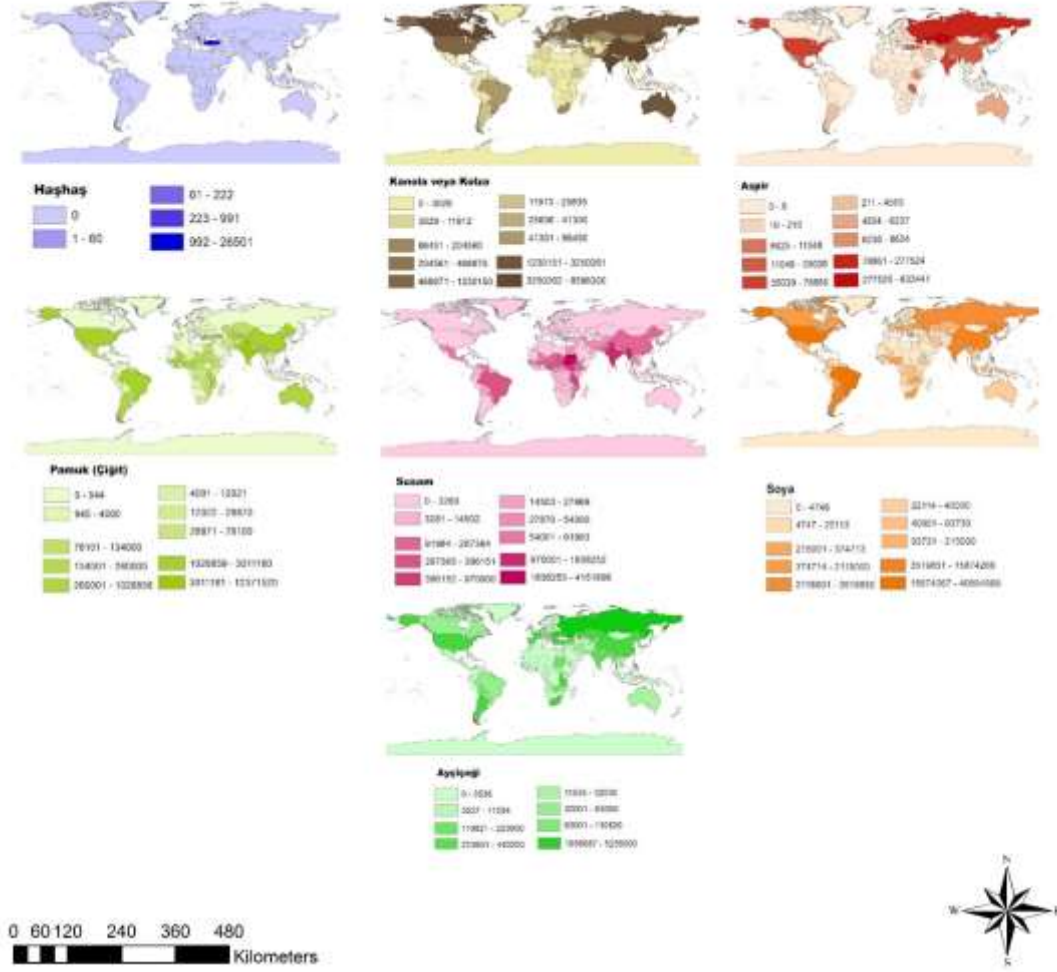


Figure 2. World oilseed crop density map by harvested area (ha)

**Şekil 2. Hasat edilen alana (ha) göre dünya yağlı tohum bitkileri yoğunluk haritası**

Verim miktarlarına bakıldığında ise hektar başına (100 g/ha) en fazla ürün elde edilen bitkiler ve elde edildiği ülkeler sırasıyla haşhaş Filistin (68.413), soya Uganda (67.970), pamuk Çin (60.406), ayçiçeği Özbekistan (50.943), kanola İrlanda (48.788), susam Afrika Cumhuriyeti (48.277) ve aspir Meksika (19.778)'dir.

Tablo 2'de ise hasat edilen alana (ha) göre dünya yağlı tohumlar tanımlayıcı istatistikleri ve 2022 yılına göre oransal değişim değerleri verilmiştir. Haşhaş bitkisinin yetiştirildiği alanlar ve buna bağlı olarak ülke sayısı çok sınırlıdır. Dünya'da yaklaşık 5 ülkede tarımı yapılmaktadır. Son 5 yıllık verilere bakıldığında ortalama en yüksek değer 2019 yılında (11.223.20 ha), en düşük değer ise 2022 yılında (5.554.80 ha) elde edilmiştir. 2019 yılının toplam hasat edilen alan içerisindeki payı %26.76 iken, bu oran 2022 yılında %13.25 değerine kadar düşmüştür. Ürün hasat edilen alan miktarlarında 2018 yılından 2022 yılına doğru genelde azalma eğilimi görülmüştür.

Kanola veya Kolza bitkisi son 5 yıllık zaman içerisinde Dünya genelinde 68 ülkede yetiştirilmiştir. Ortalama en yüksek değer 2022 yılında (694.589.11 ha), en düşük değer ise 2019 yılında (601.079.97 ha) elde edilmiştir. Genel olarak alan bazında çok önemli bir değişim yaşanmamakla birlikte bir miktar artış eğilimi göstermiştir.

Aspir son 5 yıl içerisinde sadece 23 ülkede kendine yer bulabilmiştir. Ortalama en yüksek değer 2022 yılında (53.174.08 ha), en düşük değer ise 2019 yılında (29.277.47 ha) elde edilmiştir. Diğer yağlı tohumlu bitkilerin aksine 2018 yılına göre 2022 yılında üretim alanları yaklaşık %80 oranında artış göstermiştir.

Pamuk, Dünya'da Birleşmiş Milletlere kayıtlı 208 ülkenin yaklaşık yarısına denk gelen 100 ülkede yetiştirilmektedir. Son 5 yıllık verilere bakıldığında ortalama en yüksek değer 2019 yılında (374.268.56 ha), en düşük değer ise 2022 yılında (351.268.72 ha) elde edilmiştir. Pamuk üretim alanında son 5 yıl içerisinde çok önemli bir değişimin olmadığı görülmektedir.



Susam Dünya’da yaklaşık 74 ülkede yetiştirilmektedir. Son 5 yıllık verilere bakıldığında ortalama en yüksek değer 2020 yılında (193.136.87 ha), en düşük değer ise 2018 yılında (162.224.98 ha) elde edilmiştir. Yıllık olarak bazı dönemlerde artış, bazen azalış görülmesine rağmen bu oran çok büyük bir miktarda değişim göstermemiştir.

**Tablo 1. 2022 yılı yağlı tohumlu bitkilerin en fazla tarımının yapıldığı ülkeler sıralaması**

*Table 1. Ranking of countries with the highest cultivation of oilseed crops in 2022*

| Ürünler                  | Ülkeler     | Hasat Alanı (ha) | Ülkeler    | Üretim (ton) | Ülkeler      | Verim (100g/ha) |
|--------------------------|-------------|------------------|------------|--------------|--------------|-----------------|
| Haşhaş Tohumu            | Türkiye     | 26.501           | Türkiye    | 12.240       | Filistin     | 68.413          |
|                          | Sırbistan   | 991              | Filistin   | 1.517        | Sırbistan    | 10.747          |
|                          | Filistin    | 222              | Sırbistan  | 1.065        | Makedonya    | 5.833           |
|                          | Makedonya   | 60               | Makedonya  | 35           | Türkiye      | 4.619           |
| Kanola veya Kolza Tohumu | Kanada      | 8.596.300        | Kanada     | 18.694.768   | İrlanda      | 48.788          |
|                          | Hindistan   | 7.991.420        | Çin        | 15.531.408   | Danimarka    | 44.932          |
|                          | Çin         | 7.267.007        | Hindistan  | 11.963.090   | Hollanda     | 44.813          |
|                          | Avustralya  | 3.250.261        | Avustralya | 6.820.287    | Belçika      | 42.907          |
| Aspir Tohumu             | Rusya       | 2.283.703        | France     | 4.516.540    | Almanya      | 39.468          |
|                          | Kazakistan  | 633.441          | Kazakistan | 447.457      | Meksika      | 19.778          |
|                          | Rusya       | 277.524          | Rusya      | 222.619      | Tacikistan   | 15.969          |
|                          | Hindistan   | 78.860           | Amerika    | 74.410       | Çin          | 14.746          |
| Pamuk Tohumu (Çiğit)     | Amerika     | 54.750           | Meksika    | 69.299       | Amerika      | 13.591          |
|                          | Meksika     | 35.038           | Hindistan  | 61.270       | İran         | 13.257          |
|                          | Hindistan   | 12.371.520       | Çin        | 18.121.818   | Çin          | 60.406          |
|                          | Amerika     | 3.011.180        | Hindistan  | 14.990.000   | Avustralya   | 51.034          |
| Susam Tohumu             | Çin         | 3.000.000        | Amerika    | 8.468.691    | Türkiye      | 47.974          |
|                          | Pakistan    | 2.143.605        | Brezilya   | 6.422.030    | Meksika      | 43.754          |
|                          | Brezilya    | 1.648.836        | Özbekistan | 3.500.680    | Laos         | 42.113          |
|                          | Sudan       | 4.151.896        | Sudan      | 1.231.701    | Orta Afrika  | 48.277          |
| Soya                     | Hindistan   | 1.627.040        | Hindistan  | 788.740      | Lübnan       | 35.173          |
|                          | Myanmar     | 1.538.252        | Myanmar    | 760.926      | İsrail       | 19.338          |
|                          | Tanzanya    | 970.000          | Tanzanya   | 700.000      | Özbekistan   | 18.654          |
|                          | Güney Sudan | 615.059          | Nijerya    | 450.000      | Ürdün        | 17.264          |
| Ayçiçeği Tohumu          | Brezilya    | 40.894.968       | Brezilya   | 120.701.03   | Uganda       | 67.970          |
|                          | Amerika     | 34.939.320       | Amerika    | 116.377.00   | Türkiye      | 40.780          |
|                          | Arjantin    | 15.874.266       | Arjantin   | 43.861.066   | Amerika      | 33.308          |
|                          | Hindistan   | 12.146.580       | Çin        | 20.285.000   | Kanada       | 30.893          |
| Ayçiçeği Tohumu          | Çin         | 10.243.000       | Hindistan  | 12.986.720   | Bosna Hersek | 30.000          |
|                          | Rusya       | 9.182.873        | Rusya      | 16.362.215   | Özbekistan   | 50.943          |
|                          | Ukrayna     | 5.238.000        | Ukrayna    | 11.328.740   | İsrail       | 41.357          |
|                          | Arjantin    | 1.958.686        | Arjantin   | 4.050.362    | Çin          | 30.206          |
| Ayçiçeği Tohumu          | Romanya     | 1.093.270        | Çin        | 2.930.000    | Hırvatistan  | 29.910          |
|                          | Kazakistan  | 1.090.492        | Türkiye    | 2.550.000    | Tacikistan   | 28.000          |

Soya dünyada en çok tarımı yapılan ürün durumundadır. Son 5 yıllık verilere bakıldığında ortalama en yüksek değer 2022 yılında (1.241.677.87 ha), en düşük değer ise 2019 yılında (1.177.149.34 ha) elde edilmiştir. Dünya genelinde sanayide en çok kullanılan ürün olmasına karşın 2018 yılından bu yana son 5 yıl içerisinde pek fazla bir artış göstermemiştir.

Ayçiçeği ise dünyada yaklaşık 86 ülkede yetiştirilmektedir. Son 5 yıllık verilere bakıldığında ortalama en yüksek değer 2021 yılında (349.212.55 ha), en düşük değer ise 2020 yılında (323.528.03 ha) elde edilmiştir. Ayçiçeği, dünya genelinde yıllık düzeyde ekiliş alanı en az değişen bitkilerden birisidir (Tablo 3).

Tablo 3’de ise üretime (ton) göre dünya yağlı tohumlar tanımlayıcı istatistikleri ve 2022 yılına göre oransal değişim değerleri verilmiştir. Üretim miktarlarına göre bakıldığında 2018 yılına göre yıllık değişimlerin veya artışın yağlı tohum çeşitlerinde genellikle çok büyük miktarda olmadığı görülmektedir. Kanola veya Kolza ile pamuk tohumu haricindeki diğer yağlı tohumlu bitkilerin büyük bir çoğunluğunda 2022 yılında 2018 yılına göre üretimde bir miktar azalma olduğu görülmüştür. En fazla artış yaklaşık %10.5 ile kanola veya kolza tohumu üretiminde yaşanmıştır. En büyük azalışın ise %8.60 ile susam tohumunda olduğu görülmüştür.

Tablo 4’de ise verime (100g/ha) göre dünya yağlı tohumlar tanımlayıcı istatistikleri ve 2022 yılına göre oransal değişim değerleri verilmiştir. Verim miktarlarına bakıldığında ise en fazla düşüş haşhaş veriminde görülmüştür. 2018 yılından itibaren kademeli olarak ortaya çıkan azalma 2020 ve 2021 yıllarında ortalama %21 civarında olurken bu oran 2022 yılında

neredeyse %50'ye kadar çıkmıştır. Pamuk, susam, soya ve ayçiçeği tohum verimi ortalama olarak %5-10 arasında değişim göstermekle birlikte sadece pamuk veriminde 2019 yılında %18 dolaylarında bir artış görülmüştür. Ancak sonraki yıllarda ortalamaya yakın değerler olduğu görülmüştür. Bu durumun tersine kanola veya kolza tohumu ile aspir veriminde özellikle 2022 yılında önceki yıllara oranla daha büyük miktarlarda artış gözlenmiştir.

**Tablo 2. Hasat edilen alana (ha) göre dünya yağlı tohumlar tanımlayıcı istatistikleri (FAO, 2024)**

*Table 2. Descriptive statistics of world oilseeds by harvested area (ha) (FAO, 2024)*

| Ürün Adı                 | Yıl    | Ortalama  | Toplam        | Max        | Std. Sapma | Ülke Sayısı | 2018 Yılına Göre Değişim (%) |
|--------------------------|--------|-----------|---------------|------------|------------|-------------|------------------------------|
| Haşhaş Tohumu            | 2018   | 9.273     | 46.366        | 45.123     | 20.044     | 5           |                              |
|                          | 2019   | 11.223    | 56.116        | 54.877     | 24.406     | 5           | 21.03                        |
|                          | 2020   | 7.253     | 36.266        | 35.012     | 15.523     | 5           | -21.78                       |
|                          | 2021   | 8.631     | 43.156        | 41.892     | 18.598     | 5           | -6.92                        |
|                          | 2022   | 5.555     | 27.774        | 26.501     | 11.716     | 5           | -40.10                       |
|                          | Toplam | 8.387     | 209.678       | 54.877     | 17.050     | 25          |                              |
| Kanola veya Kolza Tohumu | 2018   | 631.187   | 43.551.919    | 9.119.700  | 1.705.140  | 69          |                              |
|                          | 2019   | 601.080   | 40.873.438    | 8.471.300  | 1.657.495  | 68          | -4.77                        |
|                          | 2020   | 611.601   | 41.588.892    | 8.325.400  | 1.704.607  | 68          | -3.10                        |
|                          | 2021   | 635.996   | 43.247.704    | 8.946.200  | 1.772.371  | 68          | 0.76                         |
|                          | 2022   | 694.589   | 47.232.060    | 8.596.300  | 1.867.539  | 68          | 10.04                        |
|                          | Toplam | 634.880   | 216.494.013   | 9.119.700  | 1.732.866  | 341         |                              |
| Aspir Tohumu             | 2018   | 29.506    | 678.628       | 279.513    | 58.957     | 23          |                              |
|                          | 2019   | 29.277    | 673.382       | 262.768    | 56.731     | 23          | -0.77                        |
|                          | 2020   | 35.189    | 809.356       | 315.177    | 71.553     | 23          | 19.26                        |
|                          | 2021   | 38.375    | 882.636       | 367.970    | 87.780     | 23          | 30.06                        |
|                          | 2022   | 53.174    | 1.223.004     | 633.441    | 139.222    | 23          | 80.22                        |
|                          | Toplam | 37.104    | 4.267.006     | 633.441    | 87.090     | 115         |                              |
| Pamuk Tohumu (Çiğit)     | 2018   | 361.154   | 36.115.367    | 12.586.000 | 1.407.077  | 100         |                              |
|                          | 2019   | 374.269   | 37.426.856    | 12.614.000 | 1.435.650  | 100         | 3.63                         |
|                          | 2020   | 354.485   | 35.093.987    | 13.477.000 | 1.471.188  | 99          | -1.85                        |
|                          | 2021   | 357.365   | 35.379.129    | 13.285.890 | 1.460.908  | 99          | -1.05                        |
|                          | 2022   | 351.269   | 34.424.335    | 12.371.520 | 1.361.557  | 98          | -2.74                        |
|                          | Toplam | 359.757   | 178.439.674   | 13.477.000 | 1.422.174  | 496         |                              |
| Susam Tohumu             | 2018   | 162.225   | 12.004.649    | 3.480.960  | 484.944    | 74          |                              |
|                          | 2019   | 180.673   | 13.369.826    | 4.243.680  | 557.113    | 74          | 11.37                        |
|                          | 2020   | 193.137   | 14.292.129    | 5.173.521  | 654.575    | 74          | 19.05                        |
|                          | 2021   | 179.016   | 13.247.213    | 4.191.713  | 560.352    | 74          | 10.35                        |
|                          | 2022   | 177.083   | 13.104.140    | 4.151.896  | 551.819    | 74          | 9.16                         |
|                          | Toplam | 178.427   | 66.017.957    | 5.173.521  | 561.380    | 370         |                              |
| Soya                     | 2018   | 1.183.459 | 132.547.445   | 35.448.420 | 5.074.445  | 112         |                              |
|                          | 2019   | 1.177.149 | 130.663.577   | 35.895.207 | 4.916.491  | 111         | -0.53                        |
|                          | 2020   | 1.215.392 | 137.339.348   | 37.191.638 | 5.165.837  | 113         | 2.70                         |
|                          | 2021   | 1.218.251 | 138.880.638   | 39.126.269 | 5.317.080  | 114         | 2.94                         |
|                          | 2022   | 1.241.678 | 144.034.633   | 40.894.968 | 5.405.541  | 116         | 4.92                         |
|                          | Toplam | 1.207.536 | 683.465.641   | 40.894.968 | 5.163.048  | 566         |                              |
| Ayçiçeği Tohumu          | 2018   | 329.969   | 27.717.369    | 7.953.338  | 1.112.903  | 84          |                              |
|                          | 2019   | 331.543   | 28.181.194    | 8.414.731  | 1.137.396  | 85          | 0.48                         |
|                          | 2020   | 323.528   | 28.470.467    | 8.392.310  | 1.142.320  | 88          | -1.95                        |
|                          | 2021   | 349.213   | 30.381.492    | 9.641.346  | 1.267.925  | 87          | 5.83                         |
|                          | 2022   | 347.448   | 30.227.983    | 9.182.873  | 1.160.287  | 87          | 5.30                         |
|                          | Toplam | 336.377   | 144.978.505   | 9.641.346  | 1.160.468  | 431         |                              |
| Ara Toplam               | 2018   | 481.372   | 256.089.912   | 35.448.420 | 2.552.403  | 532         |                              |
|                          | 2019   | 478.782   | 254.712.272   | 35.895.207 | 2.478.968  | 532         | -0.54                        |
|                          | 2020   | 488.612   | 261.407.384   | 37.191.638 | 2.608.208  | 535         | 1.50                         |
|                          | 2021   | 499.885   | 266.438.628   | 39.126.269 | 2.696.850  | 533         | 3.85                         |
|                          | 2022   | 515.041   | 275.032.117   | 40.894.968 | 2.744.064  | 534         | 6.99                         |
|                          | Toplam | 492.753   | 1.313.680.313 | 40.894.968 | 2.616.034  | 2666        |                              |

Tablo 3. Üretime (ton) göre dünya yağlı tohumlar tanımlayıcı istatistikleri (FAO, 2024)

Table 3. Descriptive statistics of world oilseeds by production (ton) (FAO, 2024)

| Ürün Adı                 | Yıl    | Ortalama  | Toplam        | Max.      | Std. Sapma | Ülke Sayısı | 2018 Yılına Göre Değişim % |
|--------------------------|--------|-----------|---------------|-----------|------------|-------------|----------------------------|
| Haşhaş Tohumu            | 2018   | 23.437.25 | 93.749.00     | 70.446.00 | 31.421.33  | 4           |                            |
|                          | 2019   | 23.920.25 | 95.681.00     | 73.542.00 | 33.186.34  | 4           | 2.06                       |
|                          | 2020   | 23.181.50 | 92.726.00     | 69.253.00 | 30.794.93  | 4           | -1.09                      |
|                          | 2021   | 22.690.50 | 90.762.00     | 68.673.00 | 30.755.19  | 4           | -3.19                      |
|                          | 2022   | 22.403.00 | 89.612.00     | 68.413.00 | 30.787.54  | 4           | -4.41                      |
|                          | Toplam | 23.126.50 | 462.530.00    | 73.542.00 | 27.907.67  | 20          |                            |
| Kanola veya Kolza Tohumu | 2018   | 21.376.11 | 1.368.071.00  | 38.877.00 | 8.905.74   | 64          |                            |
|                          | 2019   | 22.759.88 | 1.456.632.00  | 44.048.00 | 9.784.33   | 64          | 6.47                       |
|                          | 2020   | 22.925.53 | 1.467.234.00  | 42.679.00 | 9.526.78   | 64          | 7.25                       |
|                          | 2021   | 22.911.48 | 1.466.335.00  | 45.476.00 | 9.548.18   | 64          | 7.18                       |
|                          | 2022   | 23.629.16 | 1.512.266.00  | 48.788.00 | 10.512.93  | 64          | 10.54                      |
|                          | Toplam | 22.720.43 | 7.270.538.00  | 48.788.00 | 9.636.95   | 320         |                            |
| Aspir Tohumu             | 2018   | 9.903.21  | 188.161.00    | 21.968.00 | 5.260.03   | 19          |                            |
|                          | 2019   | 9.975.68  | 189.538.00    | 18.562.00 | 4.913.19   | 19          | 0.73                       |
|                          | 2020   | 10.502.70 | 210.054.00    | 25.769.00 | 5.767.88   | 20          | 6.05                       |
|                          | 2021   | 9.126.32  | 173.400.00    | 16.901.00 | 4.413.40   | 19          | -7.84                      |
|                          | 2022   | 9.761.21  | 185.463.00    | 19.778.00 | 4.752.20   | 19          | -1.43                      |
|                          | Toplam | 9.860.58  | 946.616.00    | 25.769.00 | 4.963.77   | 96          |                            |
| Pamuk Tohumu (Çiğit)     | 2018   | 17.158.76 | 1.492.812.00  | 55.131.00 | 12.653.58  | 87          |                            |
|                          | 2019   | 18.262.51 | 1.588.838.00  | 68.129.00 | 13.638.68  | 87          | 6.43                       |
|                          | 2020   | 17.337.94 | 1.491.063.00  | 55.110.00 | 12.677.35  | 86          | 1.04                       |
|                          | 2021   | 18.114.09 | 1.539.698.00  | 57.349.00 | 13.863.94  | 85          | 5.57                       |
|                          | 2022   | 17.855.80 | 1.517.743.00  | 60.406.00 | 13.567.63  | 85          | 4.06                       |
|                          | Toplam | 17.744.54 | 7.630.154.00  | 68.129.00 | 13.232.37  | 430         |                            |
| Susam Tohumu             | 2018   | 9.459.99  | 681.119.00    | 74.101.00 | 10.546.82  | 72          |                            |
|                          | 2019   | 8.548.61  | 598.403.00    | 48.275.00 | 7.371.93   | 70          | -9.63                      |
|                          | 2020   | 7.898.49  | 552.894.00    | 31.667.00 | 5.314.42   | 70          | -16.51                     |
|                          | 2021   | 8.313.67  | 581.957.00    | 41.379.00 | 6.124.35   | 70          | -12.12                     |
|                          | 2022   | 8.646.74  | 622.565.00    | 48.277.00 | 6.985.65   | 72          | -8.60                      |
|                          | Toplam | 8.578.92  | 3.036.938.00  | 74.101.00 | 7.478.53   | 354         |                            |
| Soya                     | 2018   | 17.914.30 | 1.773.516.00  | 42.621.00 | 8.651.44   | 99          |                            |
|                          | 2019   | 18.403.17 | 1.821.914.00  | 42.499.00 | 8.937.71   | 99          | 2.73                       |
|                          | 2020   | 18.441.42 | 1.844.142.00  | 44.180.00 | 8.780.31   | 100         | 2.94                       |
|                          | 2021   | 18.565.93 | 1.875.159.00  | 53.174.00 | 8.866.41   | 101         | 3.64                       |
|                          | 2022   | 17.463.79 | 1.763.843.00  | 67.970.00 | 9.230.47   | 101         | -2.51                      |
|                          | Toplam | 18.157.15 | 9.078.574.00  | 67.970.00 | 8.870.32   | 500         |                            |
| Ayçiçeği Tohumu          | 2018   | 17.827.07 | 1.301.376.00  | 79.412.00 | 10.823.36  | 73          |                            |
|                          | 2019   | 17.209.93 | 1.290.745.00  | 43.784.00 | 9.231.97   | 75          | -3.46                      |
|                          | 2020   | 16.876.07 | 1.282.581.00  | 38.462.00 | 8.242.36   | 76          | -5.33                      |
|                          | 2021   | 17.386.99 | 1.304.024.00  | 37.209.00 | 8.519.73   | 75          | -2.47                      |
|                          | 2022   | 16.754.28 | 1.256.571.00  | 50.943.00 | 8.662.88   | 75          | -6.02                      |
|                          | Toplam | 17.206.68 | 6.435.297.00  | 79.412.00 | 9.089.31   | 374         |                            |
| Ara Toplam               | 2018   | 16.045.20 | 7.477.063.00  | 79.412.00 | 10.969.72  | 466         |                            |
|                          | 2019   | 16.340.34 | 7.614.597.00  | 73.542.00 | 10.960.11  | 466         | 1.84                       |
|                          | 2020   | 16.054.83 | 7.513.660.00  | 69.253.00 | 10.346.21  | 468         | 0.06                       |
|                          | 2021   | 16.255.79 | 7.607.710.00  | 68.673.00 | 10.749.19  | 468         | 1.31                       |
|                          | 2022   | 16.019.53 | 7.529.179.00  | 68.413.00 | 10.900.93  | 470         | -0.16                      |
|                          | Toplam | 16.142.95 | 37.742.209.00 | 79.412.00 | 10.779.09  | 2338        |                            |

**Tablo 4. Verime (100g/ha) göre dünya yağlı tohumlar tanımlayıcı istatistikleri (FAO, 2024)**

*Table 4. Descriptive statistics of world oilseeds by yield (100g/ha) (FAO, 2024)*

| Ürün Adı                 | Yıl    | Ortalama     | Toplam           | Max.           | Std. Sapma    | Ülke Sayısı | 2018 Yılına Göre Değişim % |
|--------------------------|--------|--------------|------------------|----------------|---------------|-------------|----------------------------|
| Haşhaş Tohumu            | 2018   | 5.929.60     | 29.648.01        | 26.991.00      | 11.792.71     | 5           |                            |
|                          | 2019   | 6.002.82     | 30.014.10        | 27.288.00      | 11.919.01     | 5           | 1.23                       |
|                          | 2020   | 4.637.15     | 23.185.73        | 20.542.00      | 8.915.80      | 5           | -21.80                     |
|                          | 2021   | 4.731.86     | 23.659.28        | 21.037.00      | 9.138.56      | 5           | -20.20                     |
|                          | 2022   | 2.971.41     | 14.857.07        | 12.240.00      | 5.222.75      | 5           | -49.89                     |
|                          | Toplam | 4.854.57     | 121.364.19       | 27.288.00      | 8.935.10      | 25          |                            |
| Kanola veya Kolza Tohumu | 2018   | 1.287.614.11 | 88.845.373.53    | 20.723.500.00  | 3.478.128.36  | 69          |                            |
|                          | 2019   | 1.254.595.81 | 85.312.515.14    | 19.912.300.00  | 3.446.578.72  | 68          | -2.56                      |
|                          | 2020   | 1.271.157.95 | 86.438.740.29    | 19.484.700.00  | 3.472.754.91  | 68          | -1.28                      |
|                          | 2021   | 1274583.55   | 86.671.681.23    | 14.713.507.68  | 3.256.212.87  | 68          | -1.01                      |
|                          | 2022   | 1511068.06   | 102.752.628.29   | 18.694.768.00  | 3.786.666.94  | 68          | 17.35                      |
|                          | Toplam | 1319709.50   | 450.020.938.48   | 20.723.500.00  | 3.472.910.60  | 341         |                            |
| Aspir Tohumu             | 2018   | 27.948.46    | 642.814.53       | 214.148.59     | 48.285.74     | 23          |                            |
|                          | 2019   | 26.980.74    | 620.557.12       | 199.789.17     | 45.068.97     | 23          | -3.46                      |
|                          | 2020   | 30.154.97    | 693.564.20       | 226.739.24     | 51.266.89     | 23          | 7.89                       |
|                          | 2021   | 28.792.01    | 662.216.25       | 223.895.45     | 54.237.40     | 23          | 3.02                       |
|                          | 2022   | 44.753.18    | 1.029.323.22     | 447.456.73     | 100.338.10    | 23          | 60.13                      |
|                          | Toplam | 31.725.87    | 3.648.475.32     | 447.456.73     | 62.479.05     | 115         |                            |
| Pamuk Tohumu (Çiğit)     | 2018   | 907.785.92   | 90.778.591.55    | 18.493.333.00  | 3.196.774.85  | 100         |                            |
|                          | 2019   | 1.071.858.46 | 107.185.846.12   | 23.504.576.00  | 4.001.283.07  | 100         | 18.07                      |
|                          | 2020   | 892.625.85   | 88.369.959.19    | 17.910.606.00  | 3.261.005.53  | 99          | -1.67                      |
|                          | 2021   | 916.800.07   | 90.763.206.83    | 17.366.363.00  | 3.232.378.43  | 99          | 0.99                       |
|                          | 2022   | 895.800.62   | 87.788.460.86    | 18.121.818.00  | 3.138.089.28  | 98          | -1.32                      |
|                          | Toplam | 937.270.29   | 464.886.064.55   | 23.504.576.00  | 3.369.601.21  | 496         |                            |
| Susam Tohumu             | 2018   | 88.852.21    | 6.575.063.62     | 960.000.00     | 193.957.93    | 74          |                            |
|                          | 2019   | 98.384.68    | 7.280.466.19     | 1.210.000.00   | 215.541.80    | 74          | 10.73                      |
|                          | 2020   | 96.464.57    | 7.138.378.39     | 1.525.104.17   | 230.297.90    | 74          | 8.57                       |
|                          | 2021   | 96.279.40    | 7.124.675.69     | 1.231.701.39   | 216.739.47    | 74          | 8.36                       |
|                          | 2022   | 97.013.17    | 7.178.974.42     | 1.231.701.39   | 215.839.05    | 74          | 9.18                       |
|                          | Toplam | 95.398.81    | 35.297.558.31    | 1.525.104.17   | 213.650.85    | 370         |                            |
| Soya                     | 2018   | 3.221.257.15 | 360.780.801.33   | 120.514.490.00 | 16.316.874.27 | 112         |                            |
|                          | 2019   | 3.189.591.02 | 354.044.603.51   | 114.316.829.00 | 15.175.958.75 | 111         | -0.98                      |
|                          | 2020   | 3.293.604.16 | 375.470.874.08   | 121.820.949.00 | 16.361.874.09 | 114         | 2.25                       |
|                          | 2021   | 3.414.542.92 | 389.257.892.74   | 134.799.179.00 | 17.511.058.39 | 114         | 6.00                       |
|                          | 2022   | 3.209.925.46 | 369.141.427.47   | 120.701.031.00 | 16.214.333.09 | 115         | -0.35                      |
|                          | Toplam | 3.266.246.64 | 1.848.695.599.13 | 134.799.179.00 | 16.280.888.78 | 566         |                            |
| Ayçiçeği Tohumu          | 2018   | 655.515.61   | 54.407.795.42    | 14.165.170.00  | 2.153.831.20  | 83          |                            |
|                          | 2019   | 695.798.52   | 58.447.075.71    | 15.379.287.40  | 2.419.024.04  | 84          | 6.15                       |
|                          | 2020   | 607.638.84   | 52.864.578.86    | 13.314.418.00  | 2.056.726.03  | 87          | -7.30                      |
|                          | 2021   | 707.483.20   | 60.843.555.43    | 16.392.410.00  | 2.492.623.92  | 86          | 7.93                       |
|                          | 2022   | 665.301.73   | 57.215.948.69    | 16.362.214.63  | 2.221.139.04  | 86          | 1.49                       |
|                          | Toplam | 666.147.78   | 283.778.954.11   | 16.392.410.00  | 2.263.713.05  | 426         |                            |
| Ara Toplam               | 2018   | 1.142.327.80 | 605.433.735.75   | 120.514.490.00 | 7.835.212.96  | 530         |                            |
|                          | 2019   | 1.167.284.77 | 616.326.358.20   | 114.316.829.00 | 7.402.652.02  | 528         | 2.18                       |
|                          | 2020   | 1.153.299.51 | 614.708.640.44   | 121.820.949.00 | 7.902.230.11  | 533         | 0.96                       |
|                          | 2021   | 1.207.980.13 | 639.021.488.78   | 134.799.179.00 | 8.451.427.60  | 529         | 5.75                       |
|                          | 2022   | 1.187.519.91 | 629.385.551.81   | 120.701.031.00 | 7.901.150.40  | 530         | 3.96                       |
|                          | Toplam | 1.171.651.24 | 3.104.875.774.98 | 134.799.179.00 | 7.899.781.06  | 2650        |                            |

#### Türkiye’de yağlı bitkilerin genel durumu

Türkiye’nin illere göre sınıflandırılmış yağlı bitkiler yoğunluk değişim haritaları Şekil 3’te, bölgelere göre ayrılmış tanımlayıcı istatistikler ise Tablo 5’de verilmiştir. Şekilde illere göre 2022 yılına ait ArcGIS yazılımında kategorilere ayırma yöntemi ile düzenlenmiş yağlı tohumlu bitkilere ait yoğunluk haritaları bulunmaktadır.

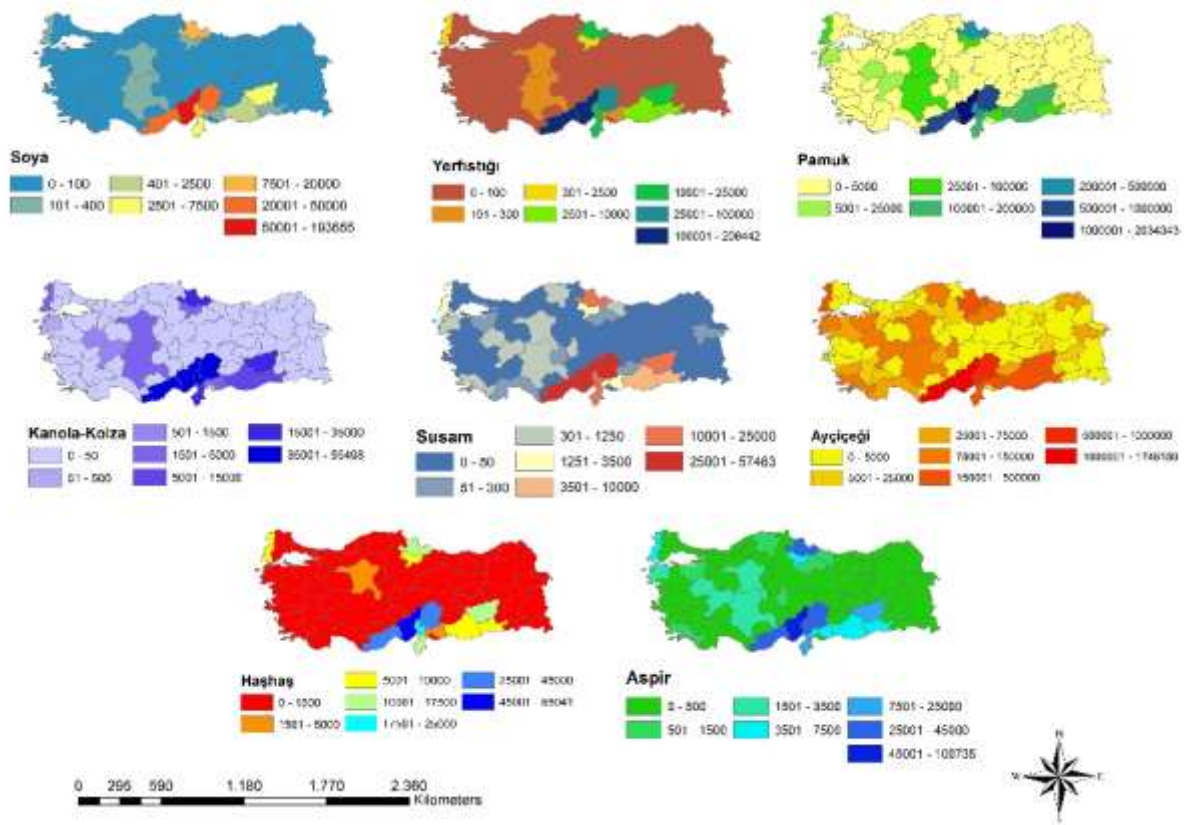


Figure 3. Turkey sunflower, peanut and cotton production according to the amount of harvested area (da)

### Şekil 3. Hasat edilen alan miktarına göre (da) Türkiye ayçiçeği, yerfıstığı ve pamuk üretimi

Tablo 5’de tüm bölgelerde elde edilen ortalama değerlerin Türkiye ortalaması (da) ile kıyaslandığında soya üretiminde Akdeniz; yerfıstığında Güneydoğu Anadolu; pamukta Akdeniz ve Ege; kanola veya kolzada İç Anadolu; susamda Akdeniz ve İç Anadolu; ayçiçeğinde Akdeniz, İç Anadolu ve Marmara; haşhaşta Akdeniz ve İç Anadolu; aspride ise İç Anadolu bölgelerinin ortalamadan çok fazla üretim alanına sahip oldukları tespit edilmiştir. Bölgesel olarak yağlı tohumlarda en fazla üretim alanına sahip ilk 3 bölgenin ise sırasıyla 1.801.105 da ile Akdeniz, 1.322.462 da ile İç Anadolu ve 1.075.908 da ile Ege bölgelerinin olduğu belirlenmiştir. Türkiye ortalamasına göre en yüksek miktarda üretimin yapıldığı yağlı tohum ve bölgesi Akdeniz bölgesinde soya olarak tespit edilmiştir. Bu bölgede Türkiye ortalamasının yaklaşık %530.24 kadar fazla bir alanda üretim yapıldığı belirlenmiştir.

Bölgedeki il sayısı bakımından en fazla yetiştiriciliği yapılan ürün Akdeniz Bölgesinde yerfıstığı, susam ve ayçiçeği; Doğu Anadolu Bölgesinde ayçiçeği ve aspir; Ege Bölgesinde susam ve ayçiçeği; Güneydoğu Anadolu Bölgesinde pamuk ve susam; İç Anadolu Bölgesinde aspir ve ayçiçeği; Karadeniz Bölgesinde ayçiçeği, soya ve aspir; Marmara Bölgesinde ayçiçeği, kanola ve kolzadır. Hemen hemen tüm bölgelerde il ölçeğinde alansal olarak çok yetiştirilen ürün (Doğu Anadolu Bölgesinde 21.729 da, Akdeniz Bölgesinde 746.169 da arasında değişmekle beraber) ise ayçiçeğidir.

Toplamda ürünlerin yetiştirildiği il sayıları bakımında ise ilk sırada ayçiçeği (59 il), ikinci sırada aspir (42 il), üçüncü sırada ise (32 il) susam gelmektedir. Alansal olarak ilk sırada ayçiçeği (3.618.226 da), ikinci sırada pamuk (1.659.601 da), üçüncü sırada ise soya (307.400 da) yer almaktadır (Tablo 5, Şekil 3).

Dünya’da hasat edilen alan (da) bakımından yağlı bitkilerin ortalama değerlerinin haşhaşta 55.848 da; kanola veya kolzada 6.945.891 da; aspride 531.740 da; pamukta 3.512.687 da; susamda 1.770.829 da; soyada 12.416.778 da ve ayçiçeğinde ise 3.474.480 da olduğu tespit edilmiştir (Tablo 2) (FAO, 2024). Türkiye ortalama değerleri ise haşhaşta 12.155,31 da; kanola veya kolzada 7840,30 da; aspride 3145,24 da; pamukta 75.436,41 da; susamda 4039,38 da; soyada 13.365,22 da ve ayçiçeğinde ise 61.325.86 da olarak tespit edilmiştir (Tablo 5) (TÜİK, 2024a). Türkiye’nin tüm yağlı bitkilerde üretim alanı (da) olarak Dünya ortalamasının çok altında kaldığı belirlenmiştir. Ortalamaya en yakın olduğu değer haşhaş üretimindedir. Türkiye üretim alanları dünya ortalamasının yaklaşık %21.88 kadarlık bir kısmını karşılayabilmektedir. Bu oran pamukta %2.15, ayçiçeğinde ise %1.77 dolaylarındadır (Tablo 5).



**Tablo 5. Türkiye'nin bölgelere göre yağlı tohumlar ekim alanı (da) tanımlayıcı istatistikleri**

*Table 5. Descriptive statistics of oilseeds cultivation area (da) of Turkey by region*

| Bölge                                    | İstatistikler | Soya      | Yerfıstığı<br>(Kabuklu) | Pamuk<br>Çekirdeği<br>(Çiğit) | Kanola<br>Veya<br>Kolza<br>Tohumu | Susam<br>Tohumu | Ayçiçeği<br>Tohumu<br>(Yağlık) | Haşhaş<br>Tohumu | Aspir<br>Tohumu |
|------------------------------------------|---------------|-----------|-------------------------|-------------------------------|-----------------------------------|-----------------|--------------------------------|------------------|-----------------|
| <b>AKDENİZ<br/>BÖLGESİ</b>               | Ortalama      | 70868.00  | 7062.29                 | 116455.40                     |                                   | 10841.00        | 111851.29                      | 13351.50         | 74.20           |
|                                          | İl Sayısı     | 4         | 7                       | 5                             |                                   | 7               | 7                              | 2                | 5               |
|                                          | Toplam        | 283472.00 | 49436.00                | 582277.00                     |                                   | 75887.00        | 782959.00                      | 26703.00         | 371.00          |
| <b>DOĞU<br/>ANADOLU<br/>BÖLGESİ</b>      | Ortalama      |           |                         |                               |                                   | 36.00           | 7798.50                        |                  | 291.67          |
|                                          | İl Sayısı     |           |                         |                               |                                   | 3               | 6                              |                  | 6               |
|                                          | Toplam        |           |                         |                               |                                   | 108.00          | 46791.00                       |                  | 1750.00         |
| <b>EGE<br/>BÖLGESİ</b>                   | Ortalama      | 35.67     | 1701.25                 | 97454.50                      | 281.00                            | 3936.78         | 41031.67                       | 11863.67         | 1393.20         |
|                                          | İl Sayısı     | 3         | 4                       | 6                             | 5                                 | 9               | 9                              | 6                | 5               |
|                                          | Toplam        | 107.00    | 6805.00                 | 584727.00                     | 1405.00                           | 35431.00        | 369285.00                      | 71182.00         | 6966.00         |
| <b>GÜNEYDOĞU<br/>ANADOLU<br/>BÖLGESİ</b> | Ortalama      | 1991.80   | 24066.00                | 49258.10                      |                                   | 316.88          | 17479.00                       |                  | 53.50           |
|                                          | İl Sayısı     | 5         | 5                       | 10                            |                                   | 8               | 5                              |                  | 2               |
|                                          | Toplam        | 9959.00   | 120330.00               | 492581.00                     |                                   | 2535.00         | 87395.00                       |                  | 107.00          |
| <b>İÇ ANADOLU<br/>BÖLGESİ</b>            | Ortalama      | 66.67     | 1.00                    |                               | 12663.50                          | 5821.00         | 82405.54                       | 13980.00         | 8673.29         |
|                                          | İl Sayısı     | 3         | 1                       |                               | 6                                 | 2               | 13                             | 3                | 14              |
|                                          | Toplam        | 200.00    | 1.00                    |                               | 75981.00                          | 11642.00        | 1071272.00                     | 41940.00         | 121426.00       |
| <b>KARADENİZ<br/>BÖLGESİ</b>             | Ortalama      | 2726.00   | 8.00                    |                               | 1483.50                           |                 | 50111.00                       | 9097.00          | 103.60          |
|                                          | İl Sayısı     | 5         | 1                       |                               | 2                                 |                 | 9                              | 2                | 5               |
|                                          | Toplam        | 13630.00  | 8.00                    |                               | 2967.00                           |                 | 450999.00                      | 18194.00         | 518.00          |
| <b>MARMARA<br/>BÖLGESİ</b>               | Ortalama      | 10.67     | 38.25                   | 16.00                         | 10921.86                          | 1219.00         | 80952.50                       |                  | 192.40          |
|                                          | İl Sayısı     | 3         | 4                       | 1                             | 7                                 | 3               | 10                             |                  | 5               |
|                                          | Toplam        | 32.00     | 153.00                  | 16.00                         | 76453.00                          | 3657.00         | 809525.00                      |                  | 962.00          |
| <b>TOPLAM</b>                            | Ortalama      | 13365.22  | 8033.32                 | 75436.41                      | 7840.30                           | 4039.38         | 61325.86                       | 12155.31         | 3145.24         |
|                                          | İl Sayısı     | 23        | 22                      | 22                            | 20                                | 32              | 59                             | 13               | 42              |
|                                          | Toplam        | 307400.00 | 176733.00               | 1659601.00                    | 156806.00                         | 129260.00       | 3618226.00                     | 158019.00        | 132100.00       |

#### Balıkesir ili yağlı tohum yoğunluk haritaları

Balıkesir ilinde son 5 yıl içerisinde tarımsal üretim türleri ve alanları ile ilgili değişimleri gösteren il düzeyindeki bilgiler *Tablo 6*'da verilmiştir. *Tablo 6* incelendiğinde toplam alanda yıllara göre çok fazla değişim (%0.75) olmamasına karşın ekilen alan ve meyve-ıçecek-baharat bitkileri kısmında bir miktar artış olduğu gözlenmiştir. Diğer bir önemli artış 2019 yılından 2022 yılına kadar süs bitkilerinde görülmüştür. Ancak 2023 yılında süs bitkileri yetiştiriciliği yapılan alanlarda yaklaşık %16 gibi önemli bir azalış olmuştur. Tabloda görüldüğü gibi özellikle nadas yapılan tarım alanlarında 2023 yılında büyük bir azalma olduğu (%53.30) görülmektedir. Böylece il düzeyinde daha fazla alanın tarıma kazanılması ile tarımsal ürün elde etme imkanı ve gelir düzeyi de artırılmış olmaktadır.

Balıkesir iline ait son 5 yıla ait ekilen alan, üretim miktarı ve verim ile ilgili istatistiki bilgiler ile 2019 yılına göre son yıllarda ortaya çıkan yüzde değişimler *Tablo 7*'de verilmiştir. Tabloda 2023 yılı verilerine göre ekilen alan bakımından (da) il ölçeğinde ilk sırada Ayçiçeği, ikinci sırada susam ve üçüncü sırada haşhaş tarımı yapıldığı görülmektedir. Ekilen alan açısından en fazla artışın yerfıstığında (%508.33), ikinci sırada pamukta (%427.01), üçüncü sırada kanola veya kolza da (%173.01) olduğu görülmüştür. Her üç artış oranı da 2021 yılında gerçekleşmiştir.

Üretim miktarlarına bakıldığında en fazla artışın ayçiçeğinde (%1270.53), ikinci sırada ise asperde (%169.14) 2022 yılında olduğu görülmektedir. Ayçiçeği ve Aspir dışındaki bitkilerin tümünde giderek azalan bir oran olduğu görülmektedir. En büyük azalış 2023 yılında kanola veya kolza da (%95.94) meydana gelmiştir. Verim değerlerinde ise en büyük artışlar 2023 yılında sırasıyla yerfıstığı (%2120) ve susam (%1000) bitkilerinde meydana gelmiştir. Bu iki ürün haricindeki tüm yağlı bitkilerde verim miktarlarında genellikle bazı yıllarda artış olduğu görülmektedir.

**Tablo 6. Balıkesir ili yıllara göre tarımsal ürün ve alan değişimi**



Table 6. Change in agricultural products and areas in Balıkesir province by year

|                         | Yıl  | Toplam alan (da) | Ekilen alan (da) | Nadas (da) | Sebze bahçeleri alanı (da) | Meyveler, içecek ve baharat bitkileri alanı (da) | Süs bitkileri alanı (da) |
|-------------------------|------|------------------|------------------|------------|----------------------------|--------------------------------------------------|--------------------------|
|                         | 2023 | 3.850.958        | 2.541.952        | 89.641     | 193.047                    | 1.025.954                                        | 364                      |
|                         | 2022 | 3.906.187        | 2.582.814        | 96.642     | 203.330                    | 1.022.913                                        | 488                      |
|                         | 2021 | 3.911.236        | 2.545.248        | 180.085    | 211.858                    | 973.554                                          | 491                      |
|                         | 2020 | 3.902.535        | 2.508.453        | 159.035    | 264.562                    | 970.024                                          | 461                      |
|                         | 2019 | 3.880.249        | 2.468.355        | 191.945    | 265.662                    | 953.852                                          | 435                      |
| 2019'a göre değişim (%) | 2023 | -0.75            | 2.98             | -53.30     | -27.33                     | 7.56                                             | -16.15                   |
|                         | 2022 | 0.67             | 4.64             | -49.65     | -23.46                     | 7.24                                             | 12.37                    |
|                         | 2021 | 0.80             | 3.12             | -6.18      | -20.25                     | 2.07                                             | 13.06                    |
|                         | 2020 | 0.57             | 1.62             | -17.15     | -0.41                      | 1.70                                             | 6.16                     |

Tablo 7. Balıkesir yağlı tohumlu bitkiler ekim alanı (da), üretim (ton) ve verim (kg/da) miktarları

Table 7. Balıkesir oilseed crops planting area (da), production (ton) and yield (kg/da) amounts

| Yağlı Tohumlu Bitkiler |                        | Yıllar |        |       |        |        | 2019 Yılına Göre % Değişim |               |                |         |
|------------------------|------------------------|--------|--------|-------|--------|--------|----------------------------|---------------|----------------|---------|
|                        |                        | 2019   | 2020   | 2021  | 2022   | 2023   | 2020                       | 2021          | 2022           | 2023    |
| Soya                   | Ekilen Alan (da)       | 11     | 6      |       |        |        | -45.45                     |               |                |         |
|                        | Hasat Edilen Alan (da) | 11     | 6      |       |        |        | -45.45                     |               |                |         |
|                        | Üretim (ton)           | 4      | 2      |       |        |        | -50.00                     |               |                |         |
|                        | Verim (kg/da)          | 364    | 333    |       |        |        | -8.52                      |               |                |         |
| Yerfıstığı             | Ekilen Alan (da)       | 12     | 19     | 73    | 8      | 9      | 58.33                      | <b>508.33</b> | -33.33         | -25.00  |
|                        | Hasat Edilen Alan (da) | 12     | 19     | 73    | 8      | 9      | 58.33                      | 508.33        | -33.33         | -25.00  |
|                        | Üretim (ton)           | 18     | 16     | 11    | 1      | 3      | -11.11                     | -38.89        | -94.44         | -83.33  |
|                        | Verim (kg/da)          | 15     | 147    | 151   | 125    | 333    | 880.00                     | 906.67        | 733.33         | 2120.00 |
| Pamuk                  | Ekilen Alan (da)       | 211    | 157    | 1112  | 166    | 151    | -25.59                     | <b>427.01</b> | -21.33         | -28.44  |
|                        | Hasat Edilen Alan (da) | 211    | 157    | 1112  | 166    | 151    | -25.59                     | 427.01        | -21.33         | -28.44  |
|                        | Üretim (ton)           | 563    | 42     | 39    | 419    | 329    | -92.54                     | -93.07        | -25.58         | -41.56  |
|                        | Verim (kg/da)          | 268    | 268    | 278   | 252    | 218    | 0.00                       | 3.73          | -5.97          | -18.66  |
| Kanola veya Kolza      | Ekilen Alan (da)       | 352    | 196    | 961   | 14776  | 1164   | -44.32                     | <b>173.01</b> | 4097.73        | 230.68  |
|                        | Hasat Edilen Alan (da) | 352    | 196    | 961   | 14776  | 1164   | -44.32                     | 173.01        | 4097.73        | 230.68  |
|                        | Üretim (ton)           | 8524   | 3233   | 2994  | 5479   | 346    | -62.07                     | -64.88        | -35.72         | -95.94  |
|                        | Verim (kg/da)          | 284    | 295    | 312   | 371    | 34     | 3.87                       | 9.86          | 30.63          | -88.03  |
| Susam                  | Ekilen Alan (da)       | 12525  | 1335   | 11917 | 1668   | 8684   | -89.34                     | -4.85         | -86.68         | -30.67  |
|                        | Hasat Edilen Alan (da) | 12495  | 1335   | 11917 | 1668   | 8684   | -89.32                     | -4.63         | -86.65         | -30.50  |
|                        | Üretim (ton)           | 625    | 78     | 576   | 565    | 479    | -87.52                     | -7.84         | -9.60          | -23.36  |
|                        | Verim (kg/da)          | 5      | 54     | 48    | 53     | 55     | 980.00                     | 860.00        | 960.00         | 1000.00 |
| Ayçiçeği               | Ekilen Alan (da)       | 18273  | 151554 | 28669 | 244886 | 259137 | 729.39                     | 56.89         | 1240.15        | 1318.14 |
|                        | Hasat Edilen Alan (da) | 18273  | 151554 | 28669 | 244886 | 259137 | 729.39                     | 56.89         | 1240.15        | 1318.14 |
|                        | Üretim (ton)           | 4177   | 3774   | 5216  | 57247  | 5271   | -9.65                      | 24.87         | <b>1270.53</b> | 26.19   |
|                        | Verim (kg/da)          | 225    | 249    | 241   | 234    | 21     | 10.67                      | 7.11          | 4.00           | -90.67  |
| Haşhaş                 | Ekilen Alan (da)       | 15489  | 4613   | 5379  | 2534   | 1762   | -70.22                     | -65.27        | -83.64         | -88.62  |
|                        | Hasat Edilen Alan (da) | 13986  | 433    | 414   | 2292   | 1762   | -96.90                     | -97.04        | -83.61         | -87.40  |
|                        | Üretim (ton)           | 645    | 264    | 144   | 95     | 78     | -59.07                     | -77.67        | -85.27         | -87.91  |
|                        | Verim (kg/da)          | 46     | 61     | 35    | 41     | 44     | 32.61                      | -23.91        | -10.87         | -4.35   |
| Aspir                  | Ekilen Alan (da)       | 648    | 3      | 375   | 1892   | 215    | -99.54                     | -42.13        | 191.98         | -66.82  |
|                        | Hasat Edilen Alan (da) | 648    | 3      | 375   | 1892   | 215    | -99.54                     | -42.13        | 191.98         | -66.82  |
|                        | Üretim (ton)           | 81     | 37     | 46    | 218    | 78     | -54.32                     | -43.21        | <b>169.14</b>  | -3.70   |
|                        | Verim (kg/da)          | 125    | 123    | 123   | 115    | 122    | -1.60                      | -1.60         | -8.00          | -2.40   |

Coğrafi Bilgi Sistemleri ve TÜİK (2024a) verilerinden yararlanılarak Balıkesir ili yağlı tohumlu bitkilerin ekiliş alanları yoğunluk haritaları ilçeler bazında ele edilmiştir. Bu amaçla ilçelere ait verilerle yoğunluk haritaları o ilçedeki veri sayısı sıklığına göre 3-10 sınıf aralığı olacak şekilde oluşturulmuştur. Şekil 4'de Pamuk bitkisine ait yoğunluk haritaları verilmiştir.

Pamuk yoğunluk haritasına bakıldığında sadece iki ilçesinde (Ayvalık ve Bigadiç) yetiştiricilik yapıldığı görülmektedir. Ayvalık'ta 2023 yılında 1500 da alanda üretim yapılırken, Bigadiç'te ise 10 da alanda tarım yapılmaktadır. Ülke ortalaması olan 75.436 da alana göre ilde yaklaşık %2'lik kısmı karşılanabilmektedir. Tablo 7 incelendiğinde ildeki yıllık pamuk ekim alanı 2019 yılına göre 2021 yılında yaklaşık 5 kat artış gözlemlenmiştir. Ancak 2022 ve 2023 yıllarında ise tam tersi yönde yaklaşık %33 ve %25 oranlarında azalma olmuştur.

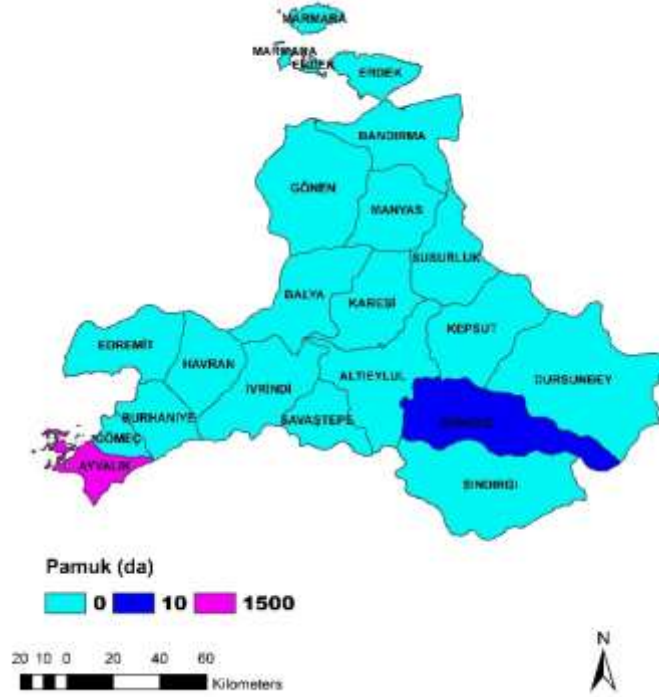


Figure 4. Balıkesir province cotton planting area density map

**Şekil 4. Balıkesir ili pamuk ekiliş alanı yoğunluk haritası**

Şekil 5’de kanola veya kolza bitkilerine ait yoğunluk haritaları verilmiştir. Haritaya bakıldığında Bandırma, Gönen ve Manyas ilçelerinde tarımın yapıldığı görülmektedir. İl bazında 2023 yılında üretimi yapılan toplam 1.164 da alanlık bölge Türkiye ortalamasının (7.840 da) yaklaşık %14’lük kısmını karşılayabilmektedir. Pamuk ekiliş alanları ile kıyaslandığında daha geniş bir alanda tarımın yapıldığı görülmektedir. İldeki ekiliş alanı önceki yıllara göre giderek artış eğilimindedir.



Figure 5. Canola and rapeseed planting area density map of Balıkesir province

**Şekil 5. Balıkesir ili kanola veya kolza ekiliş alanı yoğunluk haritası**

Şekil 6’da susam bitkisine ait alansal yoğunluk haritası verilmiştir. Haritada görüldüğü gibi ürün toplam il alanının yaklaşık yarısından fazlasında yetiştirilmektedir. İl bazında 2023 yılında 8.664 dekarlık ekiliş alanı ile Türkiye ortalamasının (4.039 da)

yaklaşık 2 katından daha fazla bir kısmını karşılamaktadır. Buna rağmen ildeki susam ekiliş alanı 2020-2023 arası tüm yıllarda azalış göstermesine rağmen, 2019 yılından sonra özellikle 2022 ve 2023 yıllarında çok büyük miktarda azaldığı belirlenmiştir.

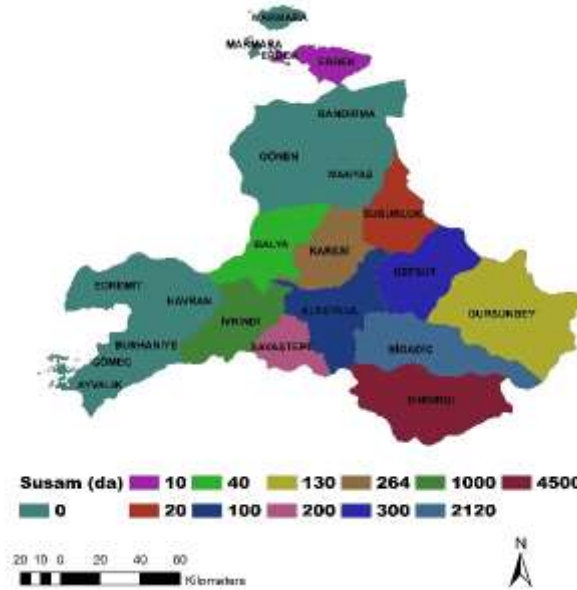


Figure 6. Balıkesir province sesame planting area density map

**Şekil 6. Balıkesir ili susam ekiliş alanı yoğunluk haritası**

Şekil 7’de Ayçiçeği bitkisine ait yoğunluk haritası verilmiştir. Ayçiçeği tarımı ilde 13 ilçede yapılmaktadır. İl bazında 2023 yılında 259.137 dekarlık ekiliş alanı ile Türkiye ortalamasının (61.325 da) yaklaşık 4 katına denk gelmektedir. 2019 (18.273 da) yılına göre ayçiçeği ekiliş alanları 2023 (259.137 da) yılında %1400 gibi çok büyük bir oranda artış göstermiştir. Bunda verilen desteklerin payının büyük olduğu söylenebilmektedir.

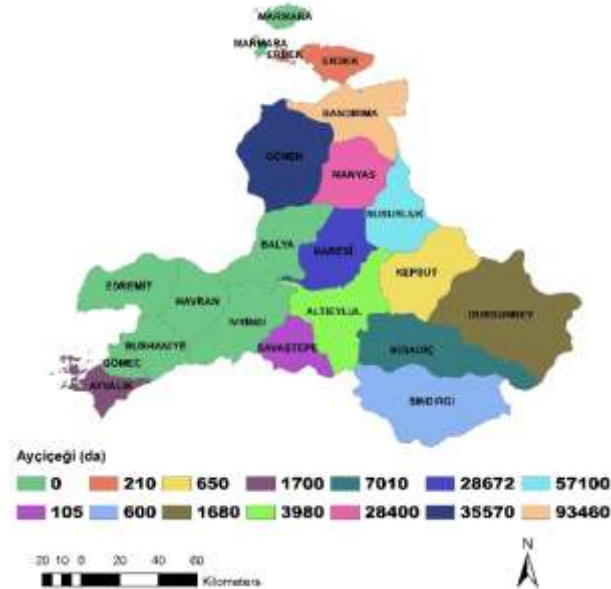


Figure 7. Sunflower planting area density map of Balıkesir province

**Şekil 7. Balıkesir ili ayçiçeği ekiliş alanı yoğunluk haritası**

Şekil 8’de haşhaş bitkisine ait yoğunluk haritası verilmiştir. İlde 3 ilçede haşhaş yetiştiriciliğinin yapıldığı görülmektedir. 2023 yılı verilerine göre 1.762 dekarlık ekiliş alanı ile Türkiye ortalamasının (12.155 da) yaklaşık %14.49’luk bir kısmını

karşılamaktadır. 2019 yılı (15.489 da) ildeki en yüksek tarım alanına sahip yıl olarak görülmektedir. Sonraki yıllarda giderek azalmış ve 2023 yılında bu değer çok fazla miktarda azalarak 1.762 dekar kadar düşmüştür.

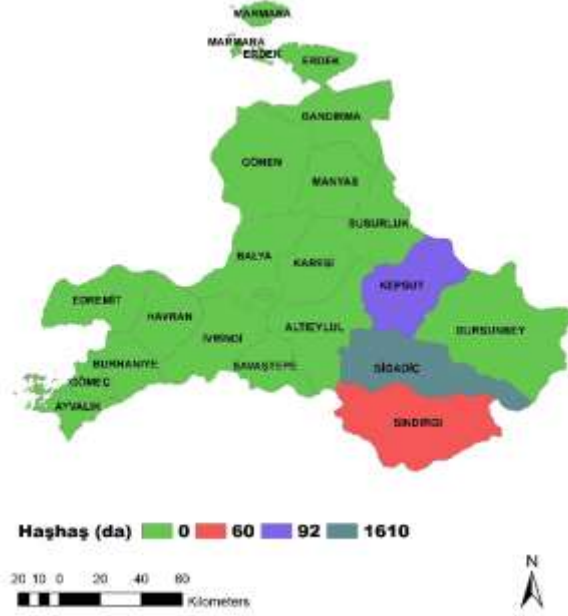


Figure 8. Poppies cultivation area density map of Balıkesir province

**Şekil 8. Balıkesir ili haşhaş ekiliş alanı yoğunluk haritası**

Şekil 9’da Aspir bitkisine ait yoğunluk haritası verilmiştir. Aspir tarımı ilde 3 ilçede yapılmaktadır. 2023 yılı verisine göre 215 dekarlık ekiliş alanı ile Türkiye ortalamasının (3145,24 da) yaklaşık %6.83’lük kısmına karşılayabilmektedir. 2019 (648 da) yılına göre aspir ekiliş alanları 2022 (1.892 da) yılında %300 gibi çok büyük bir oranda artış göstermiştir. Ancak 2023 yılında 215 dekarlık bir alanda tarımın yapıldığı görülmektedir. Bu değer 2019 yılı ile kıyaslandığında yaklaşık olarak % 300 oranında bir azalış denk gelmektedir. Yine benzer şekilde 2023 yılına ait 215 dekarlık alan 2022 yılındaki 1.892 dekarlık değer ile kıyaslandığında ise yaklaşık %780 oranında bir azalışa denk gelmektedir.

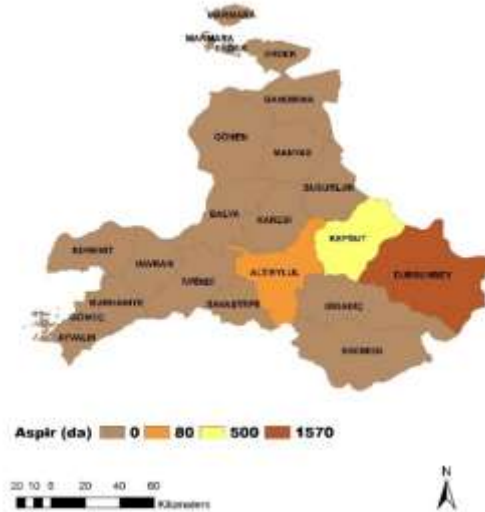


Figure 9. Balıkesir province safflower plantation area density map

**Şekil 9. Balıkesir ili aspir ekiliş alanı yoğunluk haritası**

Şekil 10’da Yerfıstığı bitkisine ait yoğunluk haritası verilmiştir. Yerfıstığı tarımı ilde sadece 2 ilçede yapılmaktadır. İl bazında 2023 yılı verilerine göre 9 dekarlık ekiliş alanı ile Türkiye ortalamasının (8.033 da) yaklaşık %1’lik kısmına denk gelmektedir. 2019 (12 da) yılına göre yerfıstığı ekiliş alanları 2022 (8 da) yılında %33 gibi bir azalış göstermiştir. Sadece 2021 yılında 73 dekar

alandan yapılan üretim ile önceki yıllara göre tarım alanlarında artış olduğu görülmektedir. Ancak haşhaş bitkisinde olduğu gibi yerfistiği tarım alanları da giderek azalmıştır.

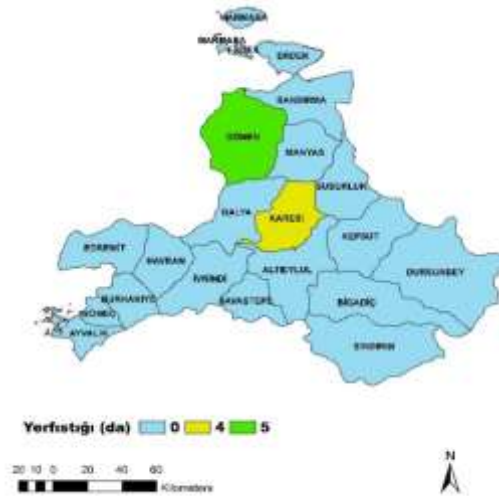


Figure 10. Balıkesir province peanut planting area density map

**Şekil 10. Balıkesir ili yerfıstığı ekiliş alanı yoğunluk haritası**

## 4. Sonuç

Türkiye ve Balıkesir ilinin yağlı tohum üretim potansiyelinin son zamanlarda yaygın olarak kullanılan CBS yardımıyla ortaya konulması amacıyla yapılan bu çalışmada, soya üretiminde Akdeniz; yerfıstığında Güneydoğu Anadolu; pamukta Akdeniz ve Ege; kanola veya kolzada İç Anadolu; susamda Akdeniz ve İç Anadolu; ayçiçeğinde Akdeniz, İç Anadolu ve Marmara; haşhaşa Akdeniz ve İç Anadolu; aspirde ise İç Anadolu bölgelerinin ortalama dan çok fazla üretim alanına sahip oldukları tespit edilmiştir. Bölgesel olarak yağlı tohumlarda en fazla üretim alanına sahip ilk 3 bölgenin ise sırasıyla 1.801.105 da ile Akdeniz, 1.322.462 da ile İç Anadolu ve 1.075.908 da ile Ege bölgelerinin olduğu belirlenmiştir. Türkiye ortalamasına göre en yüksek miktarda üretimin yapıldığı yağlı tohum ve bölgesi Akdeniz bölgesinde soya olarak tespit edilmiştir. Bu bölgede Türkiye ortalamasının yaklaşık %530.24 kadar fazla bir alanda üretim yapıldığı belirlenmiştir.

Balıkesir ili 2023 yılı verilerine göre ekilen alan bakımından (da) il ölçeğinde ilk sırada Ayçiçeği, ikinci sırada susam ve üçüncü sırada haşhaş tarımı yapıldığı tespit edilmiştir. Ekilen alan açısından en fazla artışın yerfıstığında (%508.33), ikinci sırada pamukta (%427.01), üçüncü sırada kanola veya kolzada (%173.01) olduğu görülmüştür. Her üç artış oranı da 2021 yılında gerçekleşmiştir. Üretim miktarlarına bakıldığında en fazla artışın ayçiçeğinde (%1240.53), ikinci sırada ise aspirde (%169.14) 2022 yılında olduğu görülmektedir. Ayçiçeği ve Aspir dışındaki bitkilerin tümünde giderek azalan bir oran olduğu görülmektedir. En büyük azalış 2023 yılında kanola veya kolzada (%95.94) meydana gelmiştir. Verim değerlerinde ise en büyük artışlar 2023 yılında sırasıyla yerfıstığı (%2120) ve susam (%1000) bitkilerinde meydana gelmiştir. Bu iki ürün haricindeki tüm yağlı bitkilerde verim miktarlarında genellikle bazı yıllarda artış olduğu görülmektedir.

Türkiye'nin yağlı tohumlu bitkilerde kendine yeterli olmayıp iç tüketimin ancak yarıya yakını yurt içi üretimle karşılanabilmektedir. Talebin diğer yarısını ise ithalat yaparak karşılanmaktadır. Dolayısıyla her yıl önemli miktarda döviz, yağlı tohumlu bitkiler ithalatına gitmektedir. Yağlı tohumlu bitkiler dış ticaret açığı ortalaması 1 milyar 626 milyon dolardır. Türkiye'de tarım sektörüne verilen destek tutarının ortalaması ise 3 milyar 40 milyon dolardır. Yağlı tohumlu bitkilerdeki dış ticaret açığının tarıma verilen toplam destek tutarı içerisindeki payı 2017-2021 yılları ortalamasında %54.47, son yıl ise %74.61 olarak gerçekleşmiştir. Ayrıca yağlı tohumlu bitkilerde uygulanan alan bazlı ve fark ödemesi desteği yıllar itibarıyla cari fiyatlarla artsa da reel fiyatlarla bu destekler azalmıştır (Kadakoğlu ve ark., 2023).

Toplamda 3.850.958 da tarım alanına sahip Balıkesir ilinde (TÜİK, 2024a) 283.416 dekarlık bir alanda (%7.5) yağlı tohum bitki üretimi yapılmaktadır. Bu oran arttırılarak ve arazilerinin daha verimli kullanılması ile ülke düzeyinde ortaya çıkabilecek enerji ve yağ açığımız daha hızlı bir şekilde giderilebilir. Ayrıca bu sayede özellikle biyodizel üretiminde kullanılacak hammadde oranında dışarıya bağımlılık da bir parça azaltılmış olacaktır. Suyu daha az ihtiyacı olan aspir ve ayçiçeği gibi yağlı tohumlu bitkilerin nadas alanlarının tarıma kazandırılması ile daha geniş alanlarda yetiştirilmesi ülke ekonomisine de büyük miktarlarda katkı sağlayacaktır.

Kendine yeterlilik kavramı bir ülkenin gıda ihtiyaçlarını kendi yerli üretiminden karşılayabilme derecesidir (Thomson ve Metz, 1999). Türkiye’de 2017-2021 yılları ortalamasına göre yağlı tohumlu bitkilerin kendine yeterlilik oranları pamuk çiğdinde %103, kanolada %105.2, ayçiçeğinde %62.6 ve soyada %5.3’tür. Aynı yıllar itibarıyla yağlı tohumlu bitkilerde yeterlilik derecesi ortalaması %49 olup yurt içi üretim talebin ancak yarısını karşılayabilmektedir (TÜİK, 2024a).

Bitkisel yağ açığının önüne geçilmesi için yağlı tohum üretim potansiyelinin yükseltilmesine büyük ihtiyaç bulunmaktadır. Bu bakımdan, bitkisel yağ sanayinde kullanılmakta olan ayçiçeği, pamuk ve soya fasulyesinin ürün miktarının yükselişini sağlamakla beraber, diğer yağlı tohum bitkilerinin de yağ sanayinin girmesi sağlanmalıdır. Yağlı tohum üretimini arttırmada yalnızca ekiliş bölgelerinin başka kültür bitkilerinin aleyhine ekiliş bölgelerini arttırmak yerine, sulanan tarım bölgelerinin genişlemesine paralel olarak yağlı tohum ekilişlerinin genişletilmesi ve yüksek verimli olan çeşitlerin kullanılması ilk önce ele alınmalıdır.

Ülkemizin mevcut nüfusu (85.3 milyon) ve nüfus artış hızı (%0.5) (TÜİK, 2024b) dikkate alınarak geleceğe yönelik gıda ve sanayi amaçlı bitkisel yağ kullanım ihtiyacımız göz önünde bulundurulduğunda yağlı tohum üretiminin ne kadar önemli olduğu ortadadır. Bu nedenle, bitkisel yağlı tohum üretim planlamasının yapılması ve ülkemizde var olan üretim potansiyelinin iyi değerlendirilmesi, ayrıca üretime yönelik mevcut sorunların çözülmesi önem arz etmektedir.

#### **Etik Kurul Onayı**

Bu çalışma için etik kuruldan izin alınmasına gerek yoktur.

#### **Çıkar Çatışması Beyanı**

Makale yazarları olarak aramızda herhangi bir çıkar çatışması olmadığını beyan ederiz.

#### **Yazarlık Katkı Beyanı**

Planlama: Eryılmaz, T., Karaca, Ö.F., Ertuğrul, M.; Materyal ve Metot: Karaca, Ö.F., Ertuğrul, M.; Veri Toplama ve İşleme: Karaca, Ö.F.; İstatistik Analiz: Karaca, Ö.F.; Literatür Tarama: Karaca, Ö.F., Ertuğrul, M.; Makale Yazımı, İnceleme ve Düzenleme: Karaca, Ö.F., Ertuğrul, M., Eryılmaz, T.



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**Determination of Resistance to Tomato Spotted Wild Virus in Pepper Genotypes from Turkey and Nigeria Using Molecular Markers\***

Türkiye ve Nijerya Biber Genotiplerinin Moleküler Markörler Kullanılarak Domates Lekeli Solgunluk Virüsüne Dayanıklılıklarının Belirlenmesi

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**Abstract**

Pepper (*Capsicum* spp.), a key species within the *Solanaceae* family, is extensively grown across the globe for use as both a vegetable and a spice. Pepper like other agricultural crops, are vulnerable to various biotic and abiotic stress factors. To mitigate these threats, they must possess effective defense mechanisms and resistance genes. The *Tsw* gene, found in *Capsicum chinense*, confers resistance to Tomato Spotted Wilt Virus (TSWV) and is expressed as a dominant allele (*Tsw*) in many genotypes. The SCAC<sub>568</sub> CAPs marker, linked to TSWV resistance, allows for the co-dominant differentiation of resistant and susceptible pepper genotypes (RR, Rr, rr). Due to its close association with the *Tsw* gene, this marker is a valuable tool for marker-assisted selection and for screening pepper germplasm collection in pepper breeding programs. Therefore, in this study the resistance of 60 pepper local genotypes from Turkey and Nigeria to TSWV were evaluated by the SCAC<sub>568</sub> CAPs marker linked to *Tsw*. The genomic DNA of the samples was amplified with the SCAC<sub>568</sub> marker PCR protocol and then subjected to digestion with the TaqI enzyme. The digested products were resolved by electrophoresis on a 2% agarose gel and visualized under UV light. For validation purposes, three control genotypes, including *Capsicum chinense* P1152225 (homozygous resistant) and two *Capsicum annuum* genotypes (homozygous susceptible and heterozygous resistant) were included. In the marker screening, 60 pepper genotypes were evaluated, revealing that 13 of these samples were homozygous resistant (RR), 24 were heterozygous (Rr), and 23 were homozygous susceptible (rr). Amongst the tested genotypes, Nigerian pepper genotypes showed more resistance to TSWV. These results validate the utility of the SCAC<sub>568</sub> CAPs marker in pepper breeding programme for identifying genotypes with resistance or susceptibility to Tomato Spotted Wilt Virus. In addition, it is shown that, the resistant local pepper genotypes in this study can be used in the TSWV resistance breeding programme.

**Keywords:** *Capsicum* spp., TSWV, CAPs Marker, Resistance gene, SCAC<sub>568</sub>

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## Öz

Biber (*Capsicum* spp.), Solanaceae familyasının önemli bir türü olup, dünya genelinde hem sebze hem de baharat olarak yaygın bir şekilde yetiştirilmektedir. Biber, diğer tarımsal bitki türleri gibi çeşitli biyotik ve abiyotik stres faktörlerine karşı hassastır. Bu stres faktörlerine karşı hassasiyeti azaltmak için, etkili savunma mekanizmalarına ve dayanıklılık genlerine sahip olmaları gerekmektedir. *Capsicum chinense*'de bulunan *Tsw* geni, Domates Lekeli Solgunluk Virüsü'ne (TSWV) karşı dayanıklılık sağlamaktadır. Bu gen birçok genotipte dominant allel (*Tsw*) olarak bulunarak dayanıklılığı kontrol etmektedir. SCAC<sub>568</sub> CAPs markörü, TSWV dayanımı ile bağlantılı olup, dayanıklı ve hassas biber genotiplerinin (RR, Rr, rr) kodominant ayrımını sağlamaktadır. *Tsw* geni ile yakın ilişkili olan bu markör, biber ıslah programlarında biber genetik materyallerinin taranması ve markör destekli seleksiyon için değerli bir araçtır. Bu nedenle bu çalışmada, Türkiye ve Nijerya'dan 60 yerel biber genotipi TSWV'ye karşı dayanıklılık durumlarını belirlemek için SCAC<sub>568</sub> CAPs markörü ile değerlendirmiştir. Biber genotiplerinin genomik DNA'sı, SCAC<sub>568</sub> markör PCR protokolü ile çoğaltılmış ve ardından TaqI enzimi ile kesilmiştir. Kesilen PCR ürünleri, %2 agaroz jel elektroforezi ile ayrılmış ve UV ışığı altında görüntülenmiştir. Doğrulama amacıyla, *Capsicum chinense* PI152225 (homozigot dayanıklı) ve iki *Capsicum annuum* genotipi (homozigot duyarlı ve heterozigot dayanıklı) dahil olmak üzere üç kontrol genotipi kullanılmıştır. Markör taramasında 60 biber genotipi değerlendirilmiş ve bu örneklerden 13'ünün homozigot dayanıklı (RR), 24'ünün heterozigot dayanıklı (Rr), 23'ünün ise homozigot hassas (rr) olduğu ortaya çıkmıştır. Test edilen genotiplerden, Nijerya biber genotipleri TSWV'ye karşı daha fazla dayanıklılık göstermiştir. Bu sonuçlar, biber ıslahı programlarında Domates Lekeli Solgunluk Virüsüne karşı dayanıklı veya hassas genotipleri belirlemek için SCAC<sub>568</sub> CAPs markörünün kullanılabileceğini desteklemektedir. Ayrıca, çalışmada belirlenen dayanıklı yerel biber genotiplerinin TSWV'ye dayanıklılık ıslahı programlarında kullanılabileceği de gösterilmiştir.

**Anahtar Kelimeler:** *Capsicum* spp., TSWV, CAPs Markörü, Dayanım geni, SCAC<sub>568</sub>

## 1. Introduction

Pepper (*Capsicum* spp.) is extensively cultivated around the world as both a vegetable and spice crop, and it serves as a key ingredient in numerous global food industries (Bosland and Votava, 2000). The agricultural sector plays a vital role in facilitating the economic development processes within countries (Grzelak et al., 2019).

Peppers (*Capsicum* spp.) Is a member of the Solanaceae family, encompassing 25 species, and is categorized under the Solanales order (Şalk et al., 2008). Among these, five domesticated species *C. annuum*, *C. baccatum*, *C. frutescens*, *C. chinense*, and *C. pubescens* originated from the New World (McLeod et al., 1982). Regarding pepper production in Turkey, the quantities produced for various types are as follows: 1,602,457 tons of red peppers, 395,441 tons of bell peppers, 939,178 tons of long peppers, and 143,934 tons of chili peppers (TURKSTAT, 2023).

The breeding of new varieties from locally cultivated pepper populations, which are grown for diverse purposes across different regions, along with the production of certified seeds for agricultural utilization, has been investigated (Özalp et al., 2011). Research on local pepper varieties in Turkey has demonstrated that, despite being a predominantly self-pollinating species, peppers exhibit varying degrees of cross pollination. As a result, genetically diverse pepper populations have dispersed across different regions of the country, contributing to extensive genetic variation. By selecting genotypes based on fruit and plant characteristics, valuable lines have been identified, which hold potential as parental material for the development of standard cultivars and hybrid varieties (Bozokalfa, 2009).

Nigeria holds the position of the foremost pepper producer in Africa. *C. annuum* and *C. frutescens* are the most prominent species grown in significant commercial volumes in Nigeria (Falusi and Morakinyo, 2001; Madu and Uguru, 2006). Genetic diversity serves as a vital source of variation in plant breeding programs. However, the increasing use of cultivated *Capsicum* species in Nigeria may lead to the erosion of genetic elements that govern important quality traits in local pepper varieties, thus diminishing overall genetic diversity. Conducting an analysis of the genetic diversity among *Capsicum* species cultivated across various regions is essential for evaluating genetic variation, steering plant breeding initiatives, and safeguarding the sustainable management of genetic resources (Hoisington et al., 1999).

It is important to gather and preserve the germplasm of pepper and to investigate their utility in breeding programs, in particular for resistance to abiotic and biotic stress. Because the climatic factor directly impacts plant growth, influencing the nutritional composition and characteristics of the plant. In particular, precipitation and water facilitate the solubilization of nutrient elements in the soil, which enables their uptake by plants (Karaçal, 2008).

Globally, yield reductions caused by plant diseases are substantial and significant, with plant pathogenic viruses being a major contributing factor (Fauquet et al., 2005; Strange and Scott, 2005). Viral diseases have been identified as key factors that significantly impact both the quality and yield of pepper production in cultivation areas (Anandakumar et al., 2018). Tomato Spotted Wilt Virus (TSWV) has been characterized as a Tospovirus capable of rapidly disseminating in agricultural fields via the vector *Frankliniella occidentalis* (Dal Bo et al., 1999). Due to the widespread distribution of efficient thrips vectors globally, tospoviruses have emerged as a significant pathological threat to numerous vegetables, ornamental, and industrial crops (Goldbach and Peters, 1994). TSWV was initially discovered in Australia and later disseminated rapidly, with its presence subsequently recorded in many countries throughout the Americas, Europe, Asia, and Africa (Cho et al., 1989). It has been observed that this virus induces diseases in more than 900 plant species, such as tomatoes, peppers, lettuce, and tobacco, and that weeds and ornamental plants function as reservoirs for the virus (Gordillo et al., 2008). To mitigate crop losses attributed to TSWV, a range of control strategies is utilized. Nevertheless, the physical, chemical, and biological approaches employed for vector management are both difficult to apply and frequently inadequate (Rosello et al., 1996; Cebolla-Cornejo et al., 2003). Developing resistant varieties is proposed as the most effective strategy for managing TSWV (Floor, 1971). The gene governing resistance to TSWV (*Tsw*) has been located on chromosome 10 in various *C. chinense* genotypes ('PI 152225', 'PI 159236', 'CNPH 275', 'C00943', and '7204'), and this gene has been introduced into commercial *Capsicum annuum* varieties (Black et al., 1991; Costa et al., 1995; Boiteux, 1995; Moury et al., 1997; Jahn et al., 2000).

Roggero et al. (1996) examined the impact of high temperatures on the resistance of *C. chinense* 'PI 152225.' They observed a significant reduction in genetic resistance after 20 days of exposure to a constant 33°C, particularly in 16- and 30-day-old plants. The researchers hypothesized that this resistance breakdown could be due to epistatic interactions and concluded that elevated temperatures might weaken the long-term resistance of these pepper varieties, potentially affecting their cultivation in warm climates.

It has been observed that the resistant (RI) isolate, which maintains resistance, undergoes mutations over time, resulting in the development of the resistance-breaking (RB) isolate (De Ronde et al., 2013). The global use of pepper varieties containing the *Tsw* gene has facilitated the rapid development of resistance-breaking (RB) TSWV strains. These strains were first reported in the Mediterranean pepper-growing regions of Italy (Roggero et al., 1999; Roggero et al., 2002) and Spain (Margaria et al., 2004). Following this, they have also been identified in Australia (Thomas-Carroll et al., 2003), Turkey (Deligoz et al., 2014), Argentina (Ferrand et al., 2015), and California, USA (Macedo et al., 2019). While TSWV was first documented in Korea in the 2000s (Kim et al., 2004), RB strains emerged less than a decade later (Chung et al., 2012; Hoang et al., 2013).

Molecular markers linked to the *Tsw* alleles conferring resistance to TSWV have advantage in pepper breeding. To enhance the application of the TSWV resistance gene (*Tsw*) in breeding programs, (Moury et al., 2000) identified a RAPD (Randomly Amplified Polymorphic DNA) marker linked to *Tsw*. This marker was later converted into a CAPS marker SCAC<sub>568</sub> and has been employed in marker-assisted selection (MAS) approaches (Çelik et al., 2018). Researchers have demonstrated that PCR products of the SCAR marker, after digestion with XbaI, TaqI, or HaeIII enzymes, are effective for distinguishing between TSWV resistant and susceptible genotypes across different genetic backgrounds (Moury et al., 2000). The SCAC<sub>568</sub> CAPS marker, associated with the TSWV resistance gene, has been used in breeding programs to distinguish between resistant and susceptible pepper genotypes at the co-dominant level (RR, Rr, rr), as demonstrated in previous studies (Dal Bo et al., 1999; İkten, 2019).

But there is limited knowledge on resistance to TSWV of local pepper genotypes in Turkey and Nigeria that can be potential genetic resources for pepper breeding programme. Therefore, this study conducted to distinguish pepper genotypes from Turkey and Nigeria as either resistant or susceptible to Tomato Spotted Wilt Virus (TSWV) and to mitigate yield losses by integrating resistant genotypes into the pepper breeding programs.

## 2. Materials and Methods

The genetic material for *Capsicum* spp. utilized in this study was sourced from accessions provided by the National Center for Genetic Resources and Biotechnology (NACGRAB) in Nigeria and the Aegean Agricultural Research Institute Gene Bank (AARI) in Turkey. A total of 60 accessions were analyzed, comprising 39 accessions from NACGRAB and 21 from AARI (Table 1). These genetic materials were evaluated agromorphologically in the master's thesis study conducted by Aninkan (2022), and this study also aimed to determine the TSWV resistance status of promising genotypes.

In the AARI germplasm collection, 17 were classified as *Capsicum annuum* and 4 as *Capsicum frutescens*. The remaining 39 *Capsicum* spp. genotypes from Nigeria and its sub-branches are unknown. Additionally, in this study three different genotypes were used as controls: PI 152225 (*C. chinense*) from United States Department of Agriculture, USDA (USA), as a resistant homozygous genotype (RR); Demre (*C. annum*) Antalya agriculture (Turkey), a resistant heterozygous genotype (Rr); and HV12 (*C. annum*) from National Institute of Agricultural Research INRAE (INRA) (France) a susceptible homozygous genotype(rr). as illustrated in Figure 1 below.

DNA isolation from leaf samples of pepper accessions was performed using the CTAB protocol (Doyle and Doyle, 1990; Doyle, 1991). The obtained DNA samples were subjected to agarose gel electrophoresis for quality and concentration assessment, followed by PCR amplification using the CAPs marker (SCAC<sub>568</sub>) developed by (Moury et al., 2000).

In the reaction mixture, 20-30 ng µl<sup>-1</sup> genomic DNA, 3 µl 10X PCR buffer, 3 µl 2.5 mM dNTP mix, 7.5 µl 25 mM MgCl<sub>2</sub>, 1.5 µl each of forward (5' GTGCCAGAGGAGGATTAT 3') and reverse (5' GCGAGGTGGACACTGATACT 3') primers (10 pmol µl<sup>-1</sup>), and 0.75 µl (5 U µl<sup>-1</sup>) Taq polymerase enzyme were used. The PCR cycling protocol was as follows: an initial denaturation at 94°C for 3 minutes, followed by 34 cycles of denaturation at 94°C for 30 seconds, annealing at 57°C for 30 seconds, and extension at 72°C for 1



Table 1. List of Turkish and Nigerian genotypes and their collection sources.

| Number | Genotypes | Botanical name                     | Location          |
|--------|-----------|------------------------------------|-------------------|
| 1      | TR 80002  | <i>Capsicum annuum</i>             | Afyonkarahisar    |
| 2      | TR 82505  | <i>Capsicum annuum</i>             | Eskişehir         |
| 3      | TR 69128  | <i>Capsicum annuum</i>             | Aksaray           |
| 4      | TR 71080  | <i>Capsicum annuum</i>             | Kayseri           |
| 5      | TR 71412  | <i>Capsicum annuum</i>             | Yozgat            |
| 6      | TR 71414  | <i>Capsicum frutescens</i>         | Yozgat            |
| 7      | TR 71425  | <i>Capsicum frutescens</i>         | Kayseri           |
| 8      | TR 71432  | <i>Capsicum annuum</i>             | Nevşehir          |
| 9      | TR 77192  | <i>Capsicum frutescens</i>         | Tekirdağ          |
| 10     | TR 77205  | <i>Capsicum annuum</i>             | Tekirdağ          |
| 11     | TR 77211  | <i>Capsicum annuum</i>             | İstanbul          |
| 12     | TR 62538  | <i>Capsicum annuum</i>             | Balıkesir         |
| 13     | TR 61641  | <i>Capsicum annuum</i>             | Aydın             |
| 14     | TR 61673  | <i>Capsicum annuum</i>             | Muğla             |
| 15     | TR 61894  | <i>Capsicum annuum</i>             | Denizli           |
| 16     | TR 66278  | <i>Capsicum annuum</i>             | Bilecik           |
| 17     | TR 66404  | <i>Capsicum frutescens</i>         | Bilecik           |
| 18     | TR 75288  | <i>Capsicum annuum cerasiforme</i> | Erzurum           |
| 19     | TR 75326  | <i>Capsicum annuum conoides</i>    | Artvin            |
| 20     | TR 75332  | <i>Capsicum annuum conoides</i>    | Artvin            |
| 21     | TR 45440  | <i>Capsicum annuum</i>             | Şanlıurfa         |
| 22     | NGB 00703 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 23     | NGB 01864 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 24     | NGB 02621 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 25     | NGB 02642 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 26     | NGB 02634 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 27     | NGB 00700 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 28     | NGB 01852 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 29     | NGB 00624 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 30     | NGB 00609 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 31     | NGB 00198 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 32     | NGB 01851 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 33     | NGB 01650 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 34     | NGB 02619 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 35     | NGB 01854 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 36     | NGB 00620 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 37     | NGB 02618 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 38     | NGB 01848 | <i>Capsicum</i> spp. *             | Nigeria gene bank |
| 39     | NGB 00629 | <i>Capsicum</i> spp. *             | Nigeria gene bank |

**Table 1 Continued**

|    |           |                        |                   |
|----|-----------|------------------------|-------------------|
| 40 | NGB 00704 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 41 | NGB 00702 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 42 | NGB 00596 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 43 | NGB 01850 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 44 | NGB 00597 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 45 | NGB 01853 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 46 | NGB 02730 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 47 | NGB 04600 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 48 | NGB 00701 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 49 | NGB 01858 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 50 | NGB 03222 | <i>Capsicum</i> spp.   | Nigeria gene bank |
| 51 | NGB 02620 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 52 | NGB 00617 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 53 | NGB 02633 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 54 | NGB 00586 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 55 | NGB 02655 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 56 | NGB 00590 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 57 | NGB 01472 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 58 | NGB 00564 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 59 | NGB 00600 | <i>Capsicum</i> spp. * | Nigeria gene bank |
| 60 | NGB 02641 | <i>Capsicum</i> spp. * | Nigeria gene bank |

\* Pepper genotypes obtained from the National centre for genetic resources and biotechnology (NACGRAB) In Nigeria and the Aegean agricultural research institute gene bank (AARI) in Turkey.

\* Subspecies unknown

minute. This was followed by a final extension at 72°C for 5 minutes. To verify whether the PCR products were amplified, they were separated on a 1.5% agarose gel.

Subsequently, each PCR product visualized on the gel was digested with TaqI enzyme in separate tubes. For this procedure, 10 µl of the PCR product was transferred to one tube, 2 µl of TaqI enzyme (10 U µl<sup>-1</sup>) was added, then received 2 µl of 10X digestion buffer and 6 µl of nuclease-free sterile water.

The digested products were subsequently visualized using electrophoresis on a 2% agarose gel. The Gene Ruler 100 bp Plus DNA Ladder (Thermo Scientific) was used as a molecular standard.



**Figure 1. Gel image showing the PCR products of Demre, PI, and HV12 after digestion with TaqI, M: 100 bp DNA marker.**

### 3. Results and Discussion

In this research, pepper genotypes originating from Turkey and Nigeria were evaluated for their resistance to Tomato Spotted Wilt Virus (TSWV) using by the codominant CAPS marker, SCAC<sub>568</sub> which is linked to the *Tsw* gene as identified by (Moury et al., 2000). This marker was successfully used to screen the genotypes for TSWV resistance. After isolating the pepper genotypes, DNA samples were subjected to amplification using the SCAC<sub>568</sub> primer through PCR reactions. The gel electrophoresis results of the PCR products from a subset of the 60 pepper genotypes, prior to digestion with the TaqI enzyme, are shown in *Figure 2*.



**Figure 2. Representative gel image showing 568 bp PCR products generated with the SCAC 568 primer before cutting with TaqI for some of the 60 genotypes. M: 100 bp DNA marker.**

PCR products from 60 pepper genotypes were individually processed in separate tubes to evaluate each genotype's resistance and susceptibility. These products were then subjected to digestion with the restriction enzyme Taq I to distinguish the genotypes based on their resistance to Tomato Spotted Wilt Virus (TSWV). Based on the gel electrophoresis results, homozygous resistant (RR) individuals exhibited PCR products of 568 bp that were not cleaved and thus retained their original size. In contrast, heterozygous individuals showed cleavage of the sensitive alleles, producing two distinct bands at 230 bp and 330 bp, while the resistant allele remained uncut at 568 bp, resulting in a total of three DNA bands on the agarose gel. In homozygous sensitive (rr) individuals, the PCR products were completely cleaved, yielding bands of approximately 230 bp and 330 bp as (Moury et al., 2000) indicated. The study confirms the efficacy and precision of Taq I digestion in differentiating between resistant and susceptible genotypes (*Figure 3*).

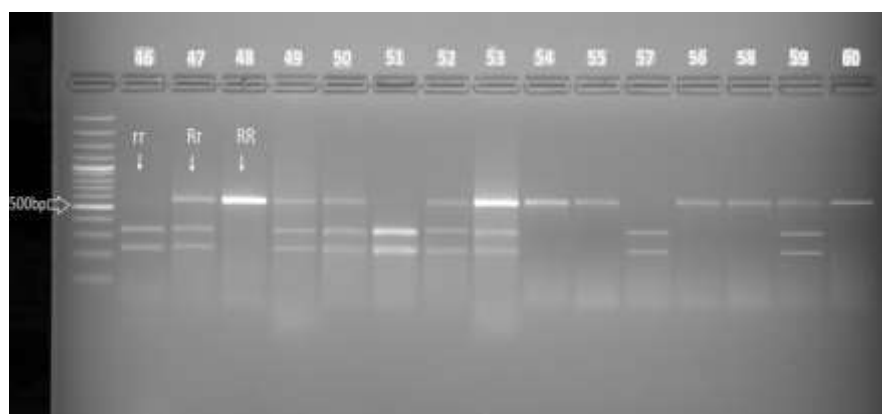


**Figure 3. Gel electrophoresis images of PCR products from 60 pepper genotypes digested with Taq I enzyme. M: 100 bp DNA marker.**

The classification of genotypes as resistant or susceptible, based on the Taq I digestion outcomes and the gel electrophoresis images of the PCR products presented in *Table 2*. The analysis identified 13 of the 60 genotypes as homozygous resistant (RR), 24 as heterozygous resistant (Rr), and 23 as homozygous susceptible (rr).

**Table 2 The outcomes of PCR product digestions performed with Taq I enzyme.**

| Genotypes | Taq1 | Genotypes | Taq1 | Genotypes | Taq1 | Genotypes | Taq1 | Genotypes | Taq1 |
|-----------|------|-----------|------|-----------|------|-----------|------|-----------|------|
| TR 80002  | rr   | TR 61641  | rr   | NGB       | rr   | NGB       | Rr   | NGB       | Rr   |
|           |      |           |      | 02642     |      | 02618     |      | 01858     |      |
| TR 82505  | rr   | TR 61673  | rr   | NGB       | RR   | NGB       | Rr   | NGB       | Rr   |
|           |      |           |      | 02634     |      | 01848     |      | 03222     |      |
| TR 69128  | rr   | TR 61894  | Rr   | NGB       | Rr   | NGB       | RR   | NGB       | rr   |
|           |      |           |      | 00700     |      | 00629     |      | 02620     |      |
| TR 71080  | rr   | TR 66278  | Rr   | NGB       | Rr   | NGB       | RR   | NGB       | Rr   |
|           |      |           |      | 01852     |      | 00704     |      | 00617     |      |
| TR 71412  | rr   | TR 66404  | Rr   | NGB       | rr   | NGB       | rr   | NGB       | Rr   |
|           |      |           |      | 00624     |      | 00702     |      | 02633     |      |
| TR 71414  | rr   | TR 75288  | rr   | NGB       | Rr   | NGB       | Rr   | NGB       | RR   |
|           |      |           |      | 00609     |      | 00596     |      | 00586     |      |
| TR 71425  | rr   | TR 75326  | rr   | NGB       | rr   | NGB       | Rr   | NGB       | RR   |
|           |      |           |      | 00198     |      | 01850     |      | 02655     |      |
| TR 71432  | rr   | TR 75332  | rr   | NGB       | Rr   | NGB       | RR   | NGB       | rr   |
|           |      |           |      | 01851     |      | 00597     |      | 00590     |      |
| TR 77192  | rr   | TR 45440  | RR   | NGB       | Rr   | NGB       | RR   | NGB       | RR   |
|           |      |           |      | 01650     |      | 01853     |      | 01472     |      |
| TR 77205  | Rr   | NGB       | Rr   | NGB       | Rr   | NGB       | rr   | NGB       | RR   |
|           |      | 00703     |      | 02619     |      | 02730     |      | 00564     |      |
| TR 77211  | rr   | NGB       | Rr   | NGB       | Rr   | NGB       | Rr   | NGB       | Rr   |
|           |      | 01864     |      | 01854     |      | 04600     |      | 00600     |      |
| TR 62538  | rr   | NGB       | Rr   | NGB       | RR   | NGB       | RR   | NGB       | RR   |
|           |      | 02621     |      | 00620     |      | 00701     |      | 02641     |      |

\* Pepper genotypes obtained from the National Centre for Genetic Resources and Biotechnology (NACGRAB) in Nigeria and the Aegean Agricultural Research Institute Gene Bank (AARI) in Turkey were digested with the TaqI enzyme.

Out of the total of 21 local genotypes from Turkey, five have been identified as resistant to the Tomato Spotted Wilt Virus (TSWV). These genotypes are TR 45440 (RR) *Capsicum annuum* from Şanlıurfa, TR 77205 (Rr) *Capsicum annuum* from Tekirdağ, TR 61894 (Rr) *Capsicum annuum* from Denizli, TR 66278 (Rr) *Capsicum annuum* from Bilecik, and finally, TR 66404 (Rr) *Capsicum frutescens* from Bilecik.

In the study, 39 pepper genotypes from Nigeria were researched (see Table 1). Among these genotypes, 32 had resistant gene see (Table 2). In these genotypes 12 Nigerian local genotypes (NGB 02634, NGB 00620, NGB 00629, NGB 00704, NGB 00597, NGB 01853, NGB 00701, NGB 00586, NGB 02655, NGB 01472, NGB 00564, and NGB 02641) were classified as resistant homozygous (RR). Meanwhile, the rest 20 resistant Nigerian genotypes (NGB 00703, NGB 01864, NGB 02621, NGB 00700, NGB 01852, NGB 00609, NGB 01851, NGB 01650, NGB 02619, NGB 01854, NGB 02618, NGB 01848, NGB 00596, NGB 01850, NGB 04600, NGB 01858, NGB 03222, NGB 00617, NGB 02633 and NGB 00600) were classified as resistant heterozygous (Rr). It can be stated that these resistant Nigerian and Turkish pepper local genotypes are highly important for breeding programs.

The higher resistance of Nigerian pepper genotypes to Tomato Spotted Wilt Virus (TSWV) can be attributed to several key factors. These include greater genetic diversity, which enhances the potential for natural resistance, species-level differences within *Capsicum* that may result in varying resistance levels, and better adaptation to local environmental conditions, including viral pressures.

Furthermore, the selection of plant species and varieties for cultivation should prioritize those that are well-adapted to the region's dominant transitional climate conditions (Atmaca, 2023). Such factors, including climate and soil type, play a crucial role in the plants' ability to resist viruses by less breaking the resistant gene. It can be also said the less introduction of hybrid pepper varieties from abroad to Nigeria resulted in less introduction of TSWV and higher maintain the genetic background of the germplasm. The development of resistant pepper cultivars through targeted breeding programs plays a vital role in promoting sustainable agricultural practices and

strengthening food security at the national level. The development of pepper varieties resistant to the Tomato Spotted Wilt Virus (TSWV) is crucial in mitigating the negative impacts of the virus, which poses a threat to farmers' livelihoods and leads to production losses.

In the breeding programs, developing pepper varieties resistant to Tomato Spotted Wilt Virus (TSWV) are of significant global importance. TSWV causes severe yield losses and economic damage in pepper production, making the development of resistant varieties crucial for food security and sustainable agriculture. Moreover, for sustainable economic development in Turkey, it is essential to prioritize the agricultural sector. Equally important is the protection of agricultural lands and the encouragement of value-added production practices. This approach will contribute to a reduction in environmental pollution and foster a positive trajectory (Çetin et al., 2020). These programs help reduce pesticide use, thereby minimizing environmental impact, and provide varieties that are resilient to increased virus spread due to climate change. Additionally, they improve farmers' livelihoods and contribute to the preservation of genetic diversity within *Capsicum* species, facilitating the development of new varieties resistant to emerging diseases. Therefore, the local pepper genotypes from Turkey and Nigeria are significant importance, particularly in the context of incorporating resistant genotypes into the breeding programs of both countries.

#### **4. Conclusions**

Our research emphasizes the genetic resistance potential of pepper genotypes to Tomato Spotted Wilt Virus (TSWV). The resistant genotypes identified from Turkey and Nigeria (13 homozygous RR and 24 heterozygous Rr) hold significant promise for inclusion in breeding programs aimed at developing new TSWV-resistant varieties. Hybridization with commercial pepper varieties could not only strengthen TSWV resistance but also enhance agronomic traits, ultimately contributing to increased food production. The robust resistance observed in Nigerian genotypes could be further investigated through genome-wide association studies (GWAS) or whole-genome sequencing. Such genetic analyses would facilitate a deeper understanding of the genetic mechanisms underpinning TSWV resistance, thereby guiding future breeding efforts. Incorporating TSWV resistance alongside other climate resilience traits, such as drought tolerance, is critical in the context of sustainable agriculture and the escalating challenges posed by climate change. Since climate change may exacerbate viral outbreaks, the development of pepper varieties that are both disease-resistant and climate-resilient is crucial for ensuring the sustainability of agricultural systems. Sharing these findings on a global platform could benefit pepper breeding initiatives in other regions. The use of the SCAC<sub>568</sub> marker for identifying resistance to additional pathogens and assessing the durability of genotypes under field conditions could further support these efforts. Lastly, establishing a long-term monitoring system in collaboration with agricultural institutions to observe the performance of resistant varieties over time and identify any potential loss of resistance would be a crucial step toward ensuring sustained agricultural productivity and resistance management.

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#### **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

#### **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

#### **Authorship Contribution Statement**

Concept: ILBI, H.; Design: ILBI, H.; Data Collection or Processing: HASSAN, A. A.; Statistical Analyses: ILBI, H.; Literature Search: HASSAN, A. A.; Writing, Review and Editing: ILBI, H., HASSAN, A. A.

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## ARAŞTIRMA MAKALESİ

## RESEARCH ARTICLE

**Evaluation of Spent Coffee Grounds as an Ecological Fertilizer for Enhancing Soil Fertility and Radish Nutrition (*Raphanus sativus* L.)**

Kahve Telvesinin Toprak Verimliliği ve Turp (*Raphanus sativus* L.) Beslenmesini Artırmada Ekolojik Bir Gübre Olarak Değerlendirilmesi

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**Abstract**

Globally, rising coffee consumption has led to an increase in coffee grounds waste. This study evaluated the feasibility of using spent coffee grounds (SCG) as an alternative fertilizer in agriculture from an environmental perspective. To this end, various application rates of coffee grounds (0, 7.5, 15, and 30 t ha<sup>-1</sup>) were tested to determine their effects on the yield and nutrient content of red radish, as well as on selected physical and chemical soil properties. Coffee grounds applications significantly increased the organic matter content and the amounts of N, P, K, Mg, and Zn in loamy sand soil following radish cultivation. Compared with the control, 30 t ha<sup>-1</sup> of SCG raised soil organic matter by 50% and enhanced P, Mg, and Mn contents by 27.5%, 14.6%, and 55.5%, respectively. SCG treatments significantly improved the P, Mg, Zn, and Mn contents in radish leaves and tubers, as well as K and vitamin C levels in the tubers. Notably, the 30 t ha<sup>-1</sup> dose increased tuber Mg and Mn contents by 32% and 55%, respectively, while the 15 t ha<sup>-1</sup> dose increased vitamin C content by 35%. However, these applications did not affect radish tuber yield, dry matter content, leaf N, Fe, and Cu levels, or tuber N, Ca, and Fe concentrations. Consequently, the application of spent coffee grounds enriched the mineral profile of radish, an important nutritional source, thereby enhancing its overall nutritional value. The findings indicate that spent coffee grounds applications to soil can improve the mineral content of both plants and soil while also enhancing soil properties, suggesting significant potential as an alternative fertilizer. Additionally, repurposing large quantities of coffee grounds in agriculture contributes to sustainable soil fertility and offers environmental benefits.

**Keywords:** Spent coffee grounds (SCG), Soil fertility, Radish, Nutrients, Vitamin C

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**Öz**

Küresel olarak kahve tüketimdeki artışlar beraberinde kahve telvesi atıklarının da artışına neden olmaktadır. Bu çalışmada çevresel bir yaklaşımla kahve telvesinin, alternatif bir gübre olarak tarımda kullanılabilirliği araştırılmıştır. Bu amaçla 0, 7.5, 15, 30 t ha<sup>-1</sup> olmak üzere farklı oranlarda uygulanan kahve telvesinin kırmızı turpun verim, besin element içeriği ve toprakların bazı fiziksel ve kimyasal özelliklerine etkileri değerlendirilmiştir. Kahve telvesi uygulamaları, turp vejetasyonu sonrası, tınlı kum tekstüre sahip topraktaki organik madde içeriğini ve bitki besin maddelerinden N, P, K, Mg, Zn miktarlarını önemli olarak artırmıştır. Kontrol ile karşılaştırıldığında 30 t ha<sup>-1</sup> kahve telvesi uygulamaları toprak organik madde içeriğini %50, P, Mg ve Mn içeriklerini sırasıyla %27.5, %14.6, %55.5 oranlarında zenginleştirmiştir. Kahve telvesi uygulamaları turp yaprak ve yumrularının P, Mg, Zn ve Mn içeriklerini önemli olarak iyileştirmiştir. Ayrıca yumruda K ve C vitamini düzeyleri de artmıştır. Özellikle, 30 t ha<sup>-1</sup> kahve telvesi dozunun yumru Mg ve Mn içeriğini sırasıyla %32, %55 oranında artırırken, 15 t ha<sup>-1</sup> dozunu ise vitamin C içeriğini %35 oranında arttırması dikkat çekici olmuştur. Turp yumru verimi, kuru madde değerleri, yapraklarının N, Fe, Cu yumruların ise N, Ca ve Fe miktarları kahve telvesi uygulamalarından etkilenmemiştir. Bu bağlamda, SCG uygulamaları, sağlıklı bir yaşam için önemli bir besin kaynağı olan turpun mineral içeriğini zenginleştirerek besin değerini artırmıştır. Araştırma sonuçları toprağa kahve telvesi uygulamalarının, bitkinin ve toprağın mineral içeriğini zenginleştirebildiğini ve toprak özelliklerini iyileştirebildiğini dolayısıyla gübre alternatifi olarak önemli bir potansiyel olduğunu ortaya koymaktadır. Ayrıca önemli miktarlara ulaşan kahve telvesi atıklarının tarımda yeniden kullanımı, sürdürülebilir toprak verimliliğine katkı sağlarken aynı zamanda çevresel açıdan da önem taşımaktadır.

**Anahtar kelimeler:** Kahve telvesi, Toprak verimliliği, Turp, Besin elementleri, C vitamini

## 1. Introduction

Coffee is one of the most widely consumed beverages globally, with millions of people drinking it every day. This high demand for coffee leads to a significant amount of waste generated in the form of spent coffee grounds (SCG), which is the residual waste produced after brewing coffee. In recent years, there has been an increasing interest in using SCG as a fertilizer in agriculture, as it has the potential to provide a cost-effective and environmentally friendly solution for improving soil fertility. According to the International Coffee Organization (ICO) statistics global coffee consumption in 2024 is stated as 10.8 million tons (International Coffee Organization, 2024). SCG can cause serious the environment problems due to storage requirements. They contain high levels of nitrogen, phosphorus, and potassium, as well as other nutrients such as calcium, magnesium, and iron. Additionally, they have a relatively high organic matter content, which can improve soil structure and fertility. The high levels of nitrogen in SCG make it an attractive option as a fertilizer, as nitrogen is an essential nutrient for plant growth and development. They also contain many harmful components as caffeine, tannin, and polyphenol contaminants (Cruz et al., 2012). Furthermore Mussatto et al. (2011) reported SCG contains compounds of carbohydrates (82%) and proteins (13%) with high contents of N (1.2%–2.3%), K (0.35%) and P (0.02%–0.5%). In addition, SCG contain more N and K than common organic materials such as cow manure (Kasongo et al., 2011).

However, the composition of SCG can vary greatly depending on the origin and processing method of the coffee beans, as well as the brewing method used. This variability in composition can lead to potential imbalances in nutrients, which can impact plant growth and soil fertility. Moreover, the high levels of caffeine and other alkaloids present in SCG can have toxic effects on plants.

On the other hand, the organic matter in SCG can improve soil structure, increase water-holding capacity, and enhance soil fertility. Thus, SCG have also been used as organic amendments for soils (Cruz et al., 2012 and 2015; Yamane et al., 2014; Cervera-Mata et al., 2019 and 2022; Hirooka et al., 2022). Hirooka et al. (2022) also reported that top dressing with SCG after crop germination is an efficient method for sustainable agricultural production. It can substantially reduce weed biomass if a sufficient quantity of SCG is used, and enrich the soil C and N in the long. Cruz et al. (2015) stated the positive impact of SCG as a soil amendment in lettuce physical and nutritional features. On the other hand Turek et al. (2019), emphasized that at high concentrations of SCG, plant growth was inhibited.

Considering this information, the use of SCG as a fertilizer has the potential to reduce waste and pollution, as well as provide a cost-effective solution for farmers.

The aim of this study was to investigate the effect of SCG applied to soils at different rates on radish yield and nutrient content in Loamy-Sand soil.

## 2. Materials and Methods

The study was conducted with radish plants (*Raphanus sativus* L.) in the experimental fields of the Odemis Vocational School at Ege University, Izmir (38°16' N; 27°59' E; 123 m above sea level). The spent coffee grounds (SCG) used in the study were collected from Starbucks outlets in Izmir. Additionally, Turkish coffee wastes (TSCG), which have a distinct brewing style, were also utilized to provide a broader perspective. At the beginning of the study, physical and chemical analyses were conducted on soil samples taken from the trial area and the SCG samples to be used in the research.

In the samples pH (Jackson, 1967), total soluble salt (Anonymous, 1957), CaCO<sub>3</sub> (Kacar, 1995), organic matter content (Reuterberg and Kremkurs, 1951) were determined. Total N was analyzed according to Bremner (1965), available K, Ca and Na was determined after extraction with 1 N NH<sub>4</sub>OAc using a flame photometer (Kacar, 1995) and available P was measured by a colorimeter (Olsen et al., 1954). Available Fe, Cu, Zn and Mn were extracted with 0.05 M DTPA+TEA and measured by Atomic Absorption Spectrophotometer (Lindsay and Norvell, 1978). Following dry-ashing, sample B contents were determined spectrophotometrically with the use of azomethine-H method (Wolf, 1971).

Table 1 shows the physical and chemical properties and mineral content of SCG used in the experiment. The SCG exhibited a high abundance of organic matter with a C:N ratio of 26%, acidic properties, and a substantial

supply of essential macronutrients and micronutrients required by plants. Particularly noteworthy were the significantly high levels of N, P, K, Ca, and Mg.

**Table 1. Physicochemical properties of SCG and TSCG used in the experiment**

| Parameter          | SCG   | TSCG  |
|--------------------|-------|-------|
| pH                 | 4.65  | 4.66  |
| Organic Matter (%) | 98    | 96    |
| C (%)              | 56.84 | 55.68 |
| C/N                | 26.56 | 26.64 |
| N (%)              | 2.14  | 2.09  |
| P (ppm)            | 1110  | 1036  |
| K (ppm)            | 4432  | 4301  |
| Ca (ppm)           | 1427  | 1374  |
| Mg (ppm)           | 1739  | 1675  |
| Na (ppm)           | 401   | 388   |
| Fe (ppm)           | 8.17  | 32.99 |
| Cu (ppm)           | 19.33 | 18.19 |
| Zn (ppm)           | 16.59 | 15.99 |
| Mn (ppm)           | 32.53 | 31.44 |
| B (ppm)            | 25.58 | 22.82 |
| Al (ppm)           | 1.31  | 1.65  |
| Cd (ppm)           | 0.19  | 0.18  |
| Cr (ppm)           | 0.08  | 0.06  |
| Ni (ppm)           | 0.35  | 0.45  |
| Pb (ppm)           | 2.18  | 2.16  |

Table 2 represents the physical and chemical properties of the experimental soil. This soil was slightly acidic, had no salinity problem, was low in  $\text{CaCO}_3$  and organic matter (Emerson, 1991; Charman and Roper, 2007), and had Loamy-Sand texture. The total N, Mn, contents of the soil were low, while available K, Ca, Mg and Zn were at medium level, according to Anonymous (1990) and P, Fe levels were high according to Chapman and Pratt (1961) and Anonymous, (1990). The contents of Cu were found sufficient (Anonymous, 1990).

The field experiment was designed as a randomized complete block, consisting of three replications. Additionally, mineral fertilizer and control plots were also arranged in order to compare the effects of SCG. Spent espresso coffee grounds, used as a potential plant nutrient and soil conditioner, were applied at increasing doses of 0, 7.5, 15 and 30 t ha<sup>-1</sup>, and spent Turkish coffee grounds at 7.5 t ha<sup>-1</sup>. SCG were incorporated into the soil two months prior to sowing at a depth of 15-20 cm. The amount of SCG at the lowest rate corresponded to an application of 170 kg N ha<sup>-1</sup>, in accordance with the European Union Nitrates Directive (Wiering et al., 2020). Mineral fertilizers were applied only mineral fertilizer plots at recommended doses of 120 kg N ha<sup>-1</sup>, 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and 100 kg K<sub>2</sub>O ha<sup>-1</sup>. All P fertilizer and 60% of N and K fertilizers were applied uniformly as basal fertilizers at the time of sowing, and the remaining N and K fertilizers were applied during tuber formation. The sources of the N, P, and K fertilizers were (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, TSP and K<sub>2</sub>SO<sub>4</sub> respectively. Radish seeds were sown in each plot in with a spacing of 10 cm between rows and 5-7 cm within the rows. Six treatments, including the control, were conducted in three replications across 18 plots, each measuring 0.5 m<sup>2</sup>. At the end of the vegetation, the radish tubers and leaves were harvested and samples were taken for measurement and analysis.

In order to determine the nutritional status of the plants, leaf and tuber samples were taken and dried at 65°C. In leaf and tuber samples the total N was analysed according to the modified Kjeldahl method (Bremner, 1965), and P was determined using a colorimeter after wet digestion with mixed acid (1 part HClO<sub>4</sub> + 4 parts HNO<sub>3</sub>) (Lott et al., 1956). Potassium and Ca were determined using a flame photometer, and Mg, Fe, Cu, Mn and Zn were determined using an Atomic Absorption Spectrophotometer (AAS) (Kacar and Inal, 2008). The content of Vitamin C was determined through titration with Dichlorophenol-Indophenol indicator using extracts obtained from radish tubers (Tee et al., 1988). The dry matter content in radish tubers was measured by drying in an oven

at 105°C (Kacar and Inal, 2008). At the end of the radish harvest, soil samples were collected from all plots at a depth of 0-20 cm and changes in macro- micro nutrients were determined.

The analysis of the variance was performed using the SAS statistical program, and the significant differences between treatments were compared using least squared means (JMP®, Version 16.).

**Table 2. Physical and chemical properties of experimental soil**

| Characteristic                      | Value      |
|-------------------------------------|------------|
| pH                                  | 6.56       |
| Salt (µS/cm)                        | 138.8      |
| CaCO <sub>3</sub> (%)               | 1.10       |
| Organic Matter (%)                  | 0.77       |
| Sand (%)                            | 81.12      |
| Clay (%)                            | 5.28       |
| Silt (%)                            | 13.60      |
| Texture                             | Loamy-Sand |
| Total N (%)                         | 0.05       |
| Available P (mg kg <sup>-1</sup> )  | 22.2       |
| Available K (mg kg <sup>-1</sup> )  | 154        |
| Available Ca (mg kg <sup>-1</sup> ) | 1352       |
| Available Mg (mg kg <sup>-1</sup> ) | 205        |
| Na (mg kg <sup>-1</sup> )           | 467.90     |
| Available Fe (mg kg <sup>-1</sup> ) | 6.83       |
| Available Cu (mg kg <sup>-1</sup> ) | 0.65       |
| Available Zn (mg kg <sup>-1</sup> ) | 1.17       |
| Available Mn (mg kg <sup>-1</sup> ) | 6.19       |

### 3. Results and Discussion

Changes in some chemical properties and mineral content of soils after radish harvest with applied SCG are shown in *Table 3* and *4*. Examination of *Table 3* and *4* reveals that SCG applications have statistically significantly increased the amounts of organic matter, N, P, K, Mg, Zn, and Mn in the soil, while decreasing the pH and CaCO<sub>3</sub> values. However, the effects of these applications on the EC, Ca, and Na amounts were found to be insignificant.

Soil pH, one of the most important properties affecting the availability of plant nutrients, decreased from 6.85 in the control to 6.50 with the highest dose of 30 t ha<sup>-1</sup> SCG application, indicating a reduction of 5.1%. This decrease in pH values can be associated with the acidic character of SCG. Additionally, organic acids found in SCG, such as chlorogenic acid and citric acid, can also be the reason behind the decrease in soil pH values (Khan et al., 2023). Similarly, various studies have also reported a decrease in soil pH values after SCG applications (Hardgrove and Livesley, 2016; Cervera-Mata et al., 2017, 2019 and 2023; Khan et al., 2023). Conversely, Kasango et al. (2011), reported an increase in soil pH from 5.21 to 6.24 with the application of 20 t ha<sup>-1</sup> SCG; Chrysargyris et al. (2021) recorded a 5% increase in the pH value of the growing medium, peat, from 4.68 to 5.96 with the addition of SCG. SCG applications have significantly reduced the CaCO<sub>3</sub> content of the soil. These findings are consistent with those reported by Cervera-Mata et al. (2017).

The study found no statistically significant difference in the effect on soil pH between mineral fertilizer applications and the application of 30 t ha<sup>-1</sup> of SCG. However, the SCG, which are rich in organic matter, significantly enhanced the organic matter content of the trial site soils, originally low in organic matter (P<0.05). Notably, the application of 30 tons per hectare of SCG resulted in a 50% increase in organic matter compared to the control, which was considered significant. Similarly, Cervera-Mata et al. (2017) reported that SCG applications increased the soil organic carbon content. Şenay and Tepecik (2024) stated that biochar applications enhanced the soil organic matter content; they reported that the organic matter content, measured as 1.28% in the control group, increased to 2.81% with the application of 80 t ha<sup>-1</sup> of biochar.



**Table 3. Effect of SCG on chemical properties of loamy-sand soil after harvest**

| Treatments<br>(t ha <sup>-1</sup> ) | pH     | EC<br>(mS cm <sup>-1</sup> ) | CaCO <sub>3</sub><br>(%) | Organic Matter<br>(%) |
|-------------------------------------|--------|------------------------------|--------------------------|-----------------------|
| Control                             | 6.85 a | 169                          | 1.12 a                   | 0.86 c                |
| Mineral Fertilizer                  | 6.40 b | 139                          | 0.62 b                   | 0.93 bc               |
| SCG 7.5                             | 6.83 a | 137                          | 0.79 b                   | 1.09 ab               |
| SCG 15                              | 6.73 a | 137                          | 0.82 ab                  | 1.02 bc               |
| SCG 30                              | 6.50 b | 134                          | 0.88 ab                  | 1.29a                 |
| TSCG 7.5                            | 6.74 a | 132                          | 0.82 ab                  | 1.05 bc               |
| LSD                                 | 0.19** | ns                           | 0.31*                    | 0.23*                 |

\* Significantly different at the P < 0.05 level; \*\* Significantly different at the P < 0.01 level; ns: no significant difference

**Table 4. Effect of SCG on mineral content of loamy-sand soil after harvest**

| Treatments<br>(t ha <sup>-1</sup> ) | N<br>(%)  | P<br>(mg kg <sup>-1</sup> ) | K<br>(mg kg <sup>-1</sup> ) | Ca<br>(mg kg <sup>-1</sup> ) | Mg<br>(mg kg <sup>-1</sup> ) | Cu<br>(mg kg <sup>-1</sup> ) | Zn<br>(mg kg <sup>-1</sup> ) | Mn<br>(mg kg <sup>-1</sup> ) |
|-------------------------------------|-----------|-----------------------------|-----------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| Control                             | 0.0737 ab | 22.27 d                     | 181 c                       | 1246                         | 198 b                        | 0.53 b                       | 0.57 bc                      | 6.90 b                       |
| Mineral Fertilizer                  | 0.0789 a  | 34.80 a                     | 200 abc                     | 1096                         | 200 b                        | 0.93 a                       | 0.54 bc                      | 10.19 a                      |
| SCG 7.5                             | 0.0821 a  | 25.53 c                     | 267 a                       | 1276                         | 207 ab                       | 0.54 b                       | 0.88 a                       | 6.68 b                       |
| SCG 15                              | 0.0808 a  | 27.87 c                     | 251 ab                      | 1093                         | 223 ab                       | 0.50 b                       | 0.96 a                       | 6.72 b                       |
| SCG 30                              | 0.0765 a  | 28.40 bc                    | 232 abc                     | 1144                         | 227 a                        | 0.53 b                       | 0.66 b                       | 10.73 a                      |
| TSCG 7.5                            | 0.0667 b  | 31.13 b                     | 214 bc                      | 1259                         | 206 ab                       | 0.60 b                       | 0.46 c                       | 7.15 b                       |
| LSD                                 | 0.00872*  | 3.07**                      | 5.17*                       | ns                           | 26.87*                       | 0.143**                      | 0.13**                       | 2.09**                       |

\* Significantly different at the P<0.05 level; \*\* Significantly different at the P<0.01 level; ns: no significant difference

In the research, the Total N content of the soil was significantly increased by SCG applications, but no significant difference was found between the doses. This situation could be attributed to the activation of soil microorganisms by SCG, which has a high organic matter content, and to some extent, immobilization (Cervera-Mata et al., 2022). Indeed, no statistically significant changes were observed in the nitrogen content of radish leaves and tubers with increasing SCG applications in the study. Similarly, Tarakcioglu et al. (2019) suggested in their study that the lesser effect of biochar on soil nitrogen content might be related to the insufficient duration of decomposition. In the study, with the highest application rate of 30 t ha<sup>-1</sup> SCG, the soil's available P, Mg, and Mn contents reached the highest levels after the harvest. Compared to the control, the soil P content increased by 27.5%, Mg content by 14.6%, and Mn content by 55.5% with the 30 t ha<sup>-1</sup> SCG application. However, the increase in the soil phosphorus content was 40% with the application of 7.5 t ha<sup>-1</sup> Turkish Spent Coffee Ground (TSCG), which is obtained by a different brewing method. SCG applications have significantly improved the soil's K content. Compared to the control, 47.5% increase was observed with the 7.5 t ha<sup>-1</sup> SCG application, reaching the highest value of 267 mg kg<sup>-1</sup>. The increases in these elements' amounts in the soils can be considered a reflection of SCG's high content of N, P, K, Mg, and Mn (Table 2). Similarly, Kasango et al. (2011), and Cervera-Mata et al. (2017) have reported that SCG improves the amounts of total N, available P, K, Ca, Mg in the soils; Cruz et al. (2014) and Chrysargyris et al. (2021) have additionally stated significant improvements in the availability of Fe, Cu, Zn. Cervera-Mata et al. (2023), in their study in Mediterranean soils of Spain, indicated that while SCG applications increased the N, K content in the soils, they did not affect the P content.

Post-harvest, the lowest soil pH values were observed in the plots with the 30 t ha<sup>-1</sup> SCG application, which had a similar effect as the plots treated with mineral fertilizer, and the highest amounts of available Mn were also determined. In this case, it can be considered that the decrease in soil pH values due to the highest rate of SCG applications has increased the release and availability of Mn. Kasongo et al. (2011) also reported that SCG applications raised the soil pH and immobilized Mn.

The available Fe and Cu content in soils was found to be higher in plots treated with chemical fertilizers (P<0.01). Available Fe content showed a slight increase with SCG applications when compared to the control,

but the difference between doses was not found to be statistically significant. These findings are in accordance with the results of Cervera-Mata et al. (2017). The available Zn amounts in soils have significantly increased with 7.5 and 15 t ha<sup>-1</sup> SCG applications compared to the control ( $P < 0.01$ ). The increases in available Zn content were inversely proportional to the pH reductions (Table 3 and 4). Acidic nature of SCG applied to soil increased the biological availability of zinc (Cervera-Mata et al., 2017). However, the available Zn levels were determined to be the lowest in TSCG application obtained with a different brewing method.

The nutrient element contents of radish leaves are presented in Table 5. When compared with the macro element sufficiency threshold percentages for fully developed radish leaves given by Bergmann (1993) which are N: 3-4%, P: 0.3-0.6%, K: 2.8-4.5%, Ca: 0.7-2.0%, Mg: 0.25-0.6%, and for the microelements Cu: 6-12, Zn: 20-80, Mn: 40-100 mg kg<sup>-1</sup>, it was noted that the trial plant leaves had adequate levels of N, P, Mg, Zn, Mn, slightly high levels of Ca, and that K and Cu values were slightly low in some plots. In the trial, available K values in leaves were found to be adequate in the plots treated with 15 t ha<sup>-1</sup> SCG and mineral fertilizer, while the control and other dosages of SCG application were found to be marginally low.

**Table 5. Effect of SCG applications on the nutrient element content of radish leaves**

| Treatments<br>(t ha <sup>-1</sup> ) | N<br>(%) | P<br>(%) | K<br>(%) | Ca<br>(%) | Mg<br>(%) | Fe<br>(mg kg <sup>-1</sup> ) | Cu<br>(mg kg <sup>-1</sup> ) | Zn<br>(mg kg <sup>-1</sup> ) | Mn<br>(mg kg <sup>-1</sup> ) |
|-------------------------------------|----------|----------|----------|-----------|-----------|------------------------------|------------------------------|------------------------------|------------------------------|
| Control                             | 3.4      | 0.378 b  | 2.72 b   | 2.45 a    | 0.305 ab  | 840                          | 6.28                         | 30.87 c                      | 44.81 b                      |
| Mineral<br>Fertilizer               | 3.5      | 0.427 a  | 3.42 a   | 1.96 ab   | 0.287 b   | 887                          | 5.71                         | 38.57 ab                     | 65.25 a                      |
| SCG 7.5                             | 3.5      | 0.396 ab | 2.80 b   | 2.14 ab   | 0.332 a   | 958                          | 5.50                         | 32.51 bc                     | 46.79 b                      |
| SCG 15                              | 3.3      | 0.396 ab | 2.95 ab  | 2.21 ab   | 0.318 ab  | 716                          | 5.86                         | 34.72 abc                    | 50.78 ab                     |
| SCG 30                              | 3.5      | 0.396 ab | 2.72 b   | 2.18 ab   | 0.334 a   | 801                          | 6.23                         | 39.81 a                      | 50.20 ab                     |
| TSCG 7.5                            | 3.2      | 0.394 ab | 2.66 b   | 1.76 b    | 0.323 ab  | 956                          | 5.87                         | 30.29 c                      | 44.48 b                      |
| LSD                                 | ns       | 0.044*   | 0.57*    | 0.62*     | 0.043*    | ns                           | ns                           | 6.62*                        | 15.98*                       |

\* Significantly different at the  $P < 0.05$  level; \*\* Significantly different at the  $P < 0.01$  level; ns: no significant difference

As seen in Table 5, SCG applications significantly increased leaf P, K, Mg, Zn, Mn content while reducing the levels of Ca ( $p < 0.05$ ); however, there were no significant effects on the content of N, Fe, and Cu. The increase in leaf K content was significant only at the 15 t ha<sup>-1</sup> SCG application (8.4% increase compared to the control), while the effects of other SCG doses were the same as the control. The leaf Mg content reached the highest values with 9.5% increase at 15 t ha<sup>-1</sup> and an 9% increase at 7.5 t ha<sup>-1</sup> SCG applications.

The highest leaf Zn content was determined with the 30 t ha<sup>-1</sup> SCG, recording 29% increase compared to the control. Cervera-Mata et al. (2017 and 2020), have mentioned that some polyphenols and other chelating compounds in Fresh SCG applied to the soil could mobilize Fe, Zn in the plant, thereby increasing their uptake and consequently the Fe, Zn concentrations in lettuce plants. Our research found that leaf contents of Mg and Zn were higher with SCG applications than with mineral fertilizer applications. Manganese levels were also significantly higher with 15 and 30 t ha<sup>-1</sup> SCG applications compared to the control. Consistent with our results, Cervera-Mata et al. (2019) have stated that SCG applications increased P, Mg, Zn, Mn in lettuce; Chrysargyris et al. (2021) indicated an increase in N, P, K, Cu values in cauliflower, broccoli, and cabbage. In a different study, Cervera-Mata et al. (2017) have noted that compared to the control, available potassium in lettuce increased by 45% and phosphorus by 9% with SCG applications. Jeon et al. (2024) reported in their studies on lettuce leaves that increasing SCG applications raised the contents of Na, Mg, P, K, Fe, while a reverse trend was observed in Ca, Zn, Mn contents. Contrary to lettuce, they noted that Japanese Hogfennel leaf mineral content was positively affected, especially marking a 288% increase in Fe content at the SCG dose compared to the control. Our research determined that the leaf Ca contents significantly decreased with SCG applications ( $P < 0.05$ ). Similarly, Çalışkan et al. (2020) recorded that as SCG applications increased, the concentrations of N, P, K in all components of pine seedlings rose, whereas the calcium values decreased. Differently, Cervera-Mata et al. (2019) reported that SCG applications increased the calcium content in lettuce. Cruz et al. (2014) determined that Fresh SCG applications at increasing doses from 2.5% to 20% reduced the content of macro and microelements in lettuce leaves, excluding potassium. It was noted that these reductions in the plant's mineral content were particularly high for Mg and P, up to 60%, and for Ca 40%, while an increase of up to 10% was

determined for K content. Remarkably, researchers have also reported an increase in the amounts of these elements in the soil after harvest. In our research, leaf contents of P, K, Mn were determined to be higher with mineral fertilizer applications compared to SCG (*Table 5*).

The effect of SCG applications on the nutrient element content of radish tubers is depicted in *Table 6*. It has been determined that SCG applications significantly increased the tuber content of P, K, Mg, Cu, Zn, and Mn. The highest content of Mg ( $P<0.05$ ) and Mn ( $P<0.01$ ) in radish tubers was observed with the highest dose of 30 t ha<sup>-1</sup> SCG. Compared to the control, the increases in Mg and Mn content were 32% and 55%, respectively, which were significantly higher than the increases after mineral fertilizer applications. The highest Cu content in the tubers was determined with the 7.5 t ha<sup>-1</sup> TSCG application ( $P<0.05$ ), which recorded a 45% increase compared to the control. No significant difference was found in the P, K, Zn contents of the tubers among SCG application doses. While the N, Ca, Fe contents in the tubers increased with SCG applications, these increases were not statistically significant. The fact that both leaf and tuber N content were unaffected by SCG applications, which are high in organic matter and N content, may be due to soil microorganisms using mineral nitrogen for their development and thereby immobilizing it (Cervera-Mata et al., 2019). Tuber values of P, K, Zn, Mn significantly increased with SCG applications compared to the control but were lower than those with mineral fertilizer applications (*Table 6*).

**Table 6. Effect of SCG applications on the nutrient element content of radish tubers**

| Treatments<br>(t ha <sup>-1</sup> ) | N<br>(%) | P<br>(%) | K<br>(%) | Ca<br>(%) | Mg<br>(%) | Fe<br>(mg kg <sup>-1</sup> ) | Cu<br>(mg kg <sup>-1</sup> ) | Zn<br>(mg kg <sup>-1</sup> ) | Mn<br>(mg kg <sup>-1</sup> ) |
|-------------------------------------|----------|----------|----------|-----------|-----------|------------------------------|------------------------------|------------------------------|------------------------------|
| Control                             | 1.4      | 0.337 b  | 2.81 b   | 0.3       | 0.169 b   | 293                          | 8.16 ab                      | 18.72 b                      | 13.04 c                      |
| Mineral<br>Fertilizer               | 1.9      | 0.453 a  | 4.00 a   | 0.4       | 0.214 ab  | 380                          | 6.29 ab                      | 27.68 a                      | 22.54 a                      |
| SCG 7.5                             | 2.0      | 0.377 ab | 3.26 ab  | 0.3       | 0.181 ab  | 314                          | 2.98 b                       | 19.73 ab                     | 14.50 c                      |
| SCG 15                              | 1.6      | 0.375 ab | 3.29 ab  | 0.3       | 0.195 ab  | 346                          | 6.82 ab                      | 22.62 ab                     | 15.43 bc                     |
| SCG 30                              | 1.7      | 0.398 ab | 3.54 ab  | 0.3       | 0.223 a   | 337                          | 3.64 ab                      | 24.48 ab                     | 20.27 ab                     |
| TSCG 7.5                            | 1.5      | 0.357 b  | 3.20 ab  | 0.4       | 0.215 ab  | 298                          | 11.83 a                      | 24.22 ab                     | 14.24 c                      |
| LSD                                 | ns       | 0.082*   | 0.91*    | ns        | 0.049*    | ns                           | 8.46*                        | 8.87*                        | 5.07**                       |

\* Significantly different at the  $P<0.05$  level; \*\* Significantly different at the  $P<0.01$  level; ns: no significant difference

In accordance with the enrichment of soil P, K, and Mg contents through SCG applications, an increase in these elements has also been observed in radish leaves and tubers (*Tables 4, 5 and 6*). Our findings, when compared to the study by Akay (2019), which investigated the effects of vermicompost doses on radish nutrition, indicate that radish leaves and tubers treated with SCG have noticeably higher concentrations of K and Fe, which are particularly important for nutritional value, than those treated with vermicompost. However, it has been observed that the P, Cu, Mn, Zn concentrations in leaves, and Mn, Zn levels in tubers were lower in SCG-treated plants.

Our research has determined that the concentrations of N, P, Ca, Mg, Fe, Zn, Mn were higher in the leaves than in the tubers, yet the K content was found to be higher in the tubers compared to the leaves. Similarly, Goyeneche et al. (2015) reported that the mineral content of radish leaves was higher than that of the tuber; the leaves contained five times more Ca compared to the tuber.

Applications of SCG to the soil have significantly increased the vitamin C values of radish tubers ( $P<0.05$ ) (*Table 7*). The highest vitamin C values were determined with the 15 t ha<sup>-1</sup> SCG application (22.01 mg/100g), which recorded a 35% increase compared to the control (16.28 mg/100g) (*Table 7*). Similarly, Cruz et al. (2012 and 2015) have reported that SCG applications supported the production of vitamin C in lettuce plants. The vitamin C values in radish tubers obtained with our SCG applications were found to be considerably higher than the 16.59 mg 100 g<sup>-1</sup> value determined by Goyeneche et al., 2015 for lettuce. This reveals that SCG applications enrich the vitamin C content of radish roots, which is also important for human health. Turhan and Özmen (2021) reported that organic fertilizers, compared to control and chemical fertilizer treatments, resulted in the highest vitamin C content in industrial tomatoes.

In our study, a decrease in radish tuber yield was observed with SCG applications compared to the control and mineral fertilizer applications (*Table 7*). However, this decrease was not found to be statistically significant. The inhibitory effect of SCG applications on plant growth has been observed by different researchers (Yamane et al., 2014; Hardgrove and Livesley, 2016; Cervera-Mata et al., 2017 and 2019). The growth-inhibitory effect of SCG on plants may be due to phytotoxins originating from fresh organic matter or nitrogen immobilization (Hardgrove and Livesley, 2016; Cervera-Mata et al., 2022). Additionally, caffeine, tannins and polyphenols present in SCG may negatively affect plant growth. Conversely, Cruz et al. (2012), reported that fresh SCG applied at concentrations of 2.5–10% increased lettuce biomass, whereas higher concentrations inhibited growth.

In our study, changes in the dry matter content with SCG application were not found to be statistically significant as shown in *Table 7*.

**Table 7. Effect of SCG applications on Tuber yield, dry matter and vitamin C content of radish tubers**

| Treatments<br>(t ha <sup>-1</sup> ) | Tuber yield<br>(g (m <sup>2</sup> ) <sup>-1</sup> ) | DM<br>(%) | C Vit<br>(mg 100 g <sup>-1</sup> ) |
|-------------------------------------|-----------------------------------------------------|-----------|------------------------------------|
| Control                             | 1023                                                | 12.2      | 16.28 c                            |
| Mineral Fertilizer                  | 1203                                                | 12.9      | 19.34 b                            |
| SCG 7.5                             | 990                                                 | 13.1      | 19.79 ab                           |
| SCG 15                              | 853                                                 | 12.9      | 22.01 a                            |
| SCG 30                              | 750                                                 | 12.7      | 19.06 b                            |
| TSCG 7.5                            | 983                                                 | 12.4      | 19.16 b                            |
| LSD                                 | ns                                                  | ns        | 2.53*                              |

\* Significantly different at the P<0.05 level; ns: no significant difference

#### 4. Conclusions

The use of Spent Coffee Grounds (SCG), rich in organic matter and minerals, as a soil conditioner has been shown to enhance the nutritional value of red radish by enriching its mineral content. SCG applications significantly increased the concentrations of P, K, Mg, Zn, and Mn in radish leaves and tubers. Moreover, the application of SCG improved the C vitamin content of radishes, which is crucial for healthy nutrition. However, while SCG use as a soil conditioner did not significantly affect radish tuber yield, it caused a slight reduction, possibly due to the bioactive residues such as caffeine inducing stress in the plant. Further research is required to gain a clearer understanding of this phenomenon.

At the end of the vegetation period, SCG applications significantly enriched the soil's organic matter content and concentrations of N, P, K, Mg, and Zn. Particularly, the application of 30 t ha<sup>-1</sup> SCG resulted in the highest levels of organic matter, K, Mg, and Mn in the soil.

These findings suggest that SCG is a highly effective organic soil conditioner and a valuable nutrient source for plants. Given the significant quantities of SCG generated as waste, its reuse in agriculture contributes to sustainable soil fertility and carries important environmental implications. This practice not only supports ecological and sustainable agriculture but also reduces the need for chemical fertilizers, offering economic benefits. SCG holds significant potential for the production of nutritionally rich agricultural products.

#### Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

#### Conflict of interest

The authors declare that they have no conflicts of interest.

#### Author contributions

Concept: Ceylan, Ş.; Data Collection or Processing: Ceylan, Ş., Yoldaş, F. Mordoğan, N., Bayız, O; Statistical Analyses: Mordoğan, N., Bayız, O.; Literature Search: Ceylan, Ş.; Writing, Review and Editing: Ceylan, Ş.; Authors read and approved the final manuscript.

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**Determination of The Reaction of Violet Plant (*Saintpaulia ionantha* L.) to Salinity\***Menekşe Bitkisinin (*Saintpaulia ionantha* L.) Tuza Reaksiyonunun BelirlenmesiAli Rıza DEMİRKİRAN<sup>1\*</sup>, Gülcan DEMİR POLAT<sup>2</sup>**Abstract**

Salinity causes significant crop loss every year. Excessive salinity has different effects on plant nutrition and metabolism. In this experiment, violet plants (*Saintpaulia ionantha* L.) were used and the experiment was set up in 1.5 kg pots. Plants were grown under laboratory conditions. Water containing different salt concentrations prepared from sodium chloride (S1=control=0 dS m<sup>-1</sup>, S2=2 dS m<sup>-1</sup>, S3= 4 dS m<sup>-1</sup>, S4=6 dS m<sup>-1</sup>, S5=8 dS m<sup>-1</sup> and S6=10 dS m<sup>-1</sup>) were used. After 2 months, in order to investigate the plant development, leaf area, root fresh-dry weights and leaf fresh-dry weights were measured. In addition, P, K, Ca, Na, Fe, Cu, Zn and Mn contents in the roots and leaves of violet plants were also determined. Considering the obtained data, salt doses did not have a significant effect on leaf area, leaf fresh-dry weights and P, K and Ca values in roots. It was determined that fresh-dry weights of *Saintpaulia ionantha* L. plant roots and Na, Fe, Cu, Zn and Mn contents in roots changed significantly ( $P<0.01$ ) with salt applications. It was found that salt applications decreased root fresh-dry weights. Na contents in plant roots were highest in 4 and 10 dS m<sup>-1</sup> salt applications. Mn, Zn and Fe contents in roots increased up to 8 dS m<sup>-1</sup> application, and Cu contents up to 10 dS m<sup>-1</sup> application. When the nutrient elements in the leaves were examined, it was determined that Ca and Na contents increased significantly ( $P<0.01$ ) and K contents increased but were not significant. It was found that micro elements (Mn, Zn, Cu and Fe) in plant leaves increased significantly ( $P<0.01$ ) with salt applications. The microelements increases were determined up to 10 dS m<sup>-1</sup> application in Zn, up to 8 dS m<sup>-1</sup> application in Mn and Fe, and up to 4 dS m<sup>-1</sup> application in Cu contents. According to the results obtained, it was determined that the violet plant is tolerant to salt applications up to a certain level.

**Keywords:** Violet plant (*Saintpaulia ionantha* L.), Salinity, Macro and micro elements

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## Öz

Tuzluluk her yıl önemli miktarda ürün kaybına neden olmaktadır. Aşırı tuzluluğun bitkinin beslenmesi ve metabolizması üzerinde farklı etkileri vardır. Bu denemede menekşe bitkileri (*Saintpaulia ionantha* L.) kullanılmış olup, deneme 1,5 kg'lık saksılarda kurulmuştur. Bitkiler laboratuvar şartlarında yetiştirilmiştir. Sodyum klorürden hazırlanan farklı tuz konsantrasyonlarını içeren su (S1=kontrol=0 dS m<sup>-1</sup>, S2=2 dS m<sup>-1</sup>, S3= 4 dS m<sup>-1</sup>, S4=6 dS m<sup>-1</sup>, S5=8 dS m<sup>-1</sup> ve S6=10 dS m<sup>-1</sup>) kullanılmış olup, 2 ay sonra bitkinin gelişimini incelemek amacıyla, yaprak alanı, kök taze-kuru ağırlıkları ile yaprak taze-kuru ağırlıkları ölçülmüştür. Ayrıca, menekşe bitkisinin köklerinde ve yapraklarındaki P, K, Ca, Na, Fe, Cu, Zn ve Mn içerikleri de belirlenmiştir. Elde edilen veriler dikkate alındığında, yaprak alanı, yaprak taze-kuru ağırlıkları ile kökteki P, K ve Ca değerleri üzerine tuz dozları önemli bir etkide bulunmamıştır. Menekşe köklerinin taze-kuru ağırlıkları ile köklerdeki Na, Fe, Cu, Zn ve Mn içeriklerinin tuz uygulamalarıyla önemli düzeyde ( $P<0.01$ ) değiştiği belirlenmiştir. Tuz uygulamanın kök taze-kuru ağırlıklarını düşürdüğü tespit edilmiştir. Tuzun 4 dS m<sup>-1</sup> ve 10 dS m<sup>-1</sup> uygulamalarında bitki köklerindeki Na içerikleri en yüksek çıkmıştır. Köklerdeki Mn, Zn ve Fe içerikleri 8 dS m<sup>-1</sup> uygulamasına kadar, Cu içerikleri ise 10 dS.m<sup>-1</sup> uygulamasına kadar artmıştır. Yapraktaki besin elementleri incelendiğinde, Ca ve Na içeriklerinin önemli düzeyde ( $P<0.01$ ) arttığı, K içeriklerinin de arttığı, fakat bu artışın önemli olmadığı belirlenmiştir. Tuz uygulamalarıyla bitki yapraklarındaki mikro elementlerin (Mn, Zn, Cu ve Fe) önemli düzeyde ( $P<0.01$ ) arttığı tespit edilmiştir. Mikro elementlerdeki bu artışların, çinkoda 10 dS m<sup>-1</sup> uygulamasına kadar, mangan ve demirde 8 dS m<sup>-1</sup> uygulamasına kadar, bakırda 4 dS m<sup>-1</sup> uygulamasına kadar olduğu tespit edilmiştir. Elde edilen sonuçlara göre, menekşe bitkisinin belirli bir düzeye kadar tuz uygulamalarına toleransı olduğu belirlenmiştir.

**Anahtar Kelimeler:** Menekşe bitkisi (*Saintpaulia ionantha* L.), Tuzluluk, Makro ve mikro elementler

## 1. Introduction

Nearly half of the lands in the world where irrigated agriculture is carried out and 20% of the agricultural lands in production are faced with salinity (Zhu, 2001). It is known that the salinity problem negatively affects agricultural soils and makes it difficult to obtain sufficient plant products (Demirkiran and Sohrabi, 2024). The anions that most cause salinity problems are;  $\text{Cl}^-$  and  $\text{SO}_4$ , cations;  $\text{Na}^+$ ,  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$  (Bischoff and Werner, 1999). Salt stress causes the plant's water use efficiency to decrease, salt ions to increase and stem elongation to decrease (Mandhanian et al., 2006). Salt accumulation in the soil negatively affects plant growth and yield (Blum, 1986). Salt stress affects plants in various ways, including ion toxicity and nutritional disorders (Dhakar et al., 2017). High salt concentrations also cause a decrease in the length, mass and function of roots (Shannon and Grieve 1999; Boydak et al., 2025). In leaves, it causes cell elongation and division to decrease, resulting in a decrease in leaf area (Alarcon et al., 1993). However, the most delicate and crucial stages of most plants' establishment in saline settings are during their seedling establishment (Altuner et al., 2022).

Although the reactions of plants to salt in their nutrient intake are different, these reactions can generally be summarized as follows; i) selective accumulation or removal of ions, ii) control of the uptake of ions from the roots or transport to the leaves, and iii) accumulation of ions in the cells or some parts of the plant (Parida and Das, 2005). Salt-tolerant genotypes generally can restrict Na transport to above-ground growth zones (shoots). Some tolerant genotypes can tolerate high Na concentrations in their tissues. This depends on the ion uptake of plants, the species genotype, the salinity level and the chemical composition of the soil solution (Niu and Rodriguez, 2008).

In general, decreases are observed in many physiological characteristics of ornamental plants exposed to salt stress. Among these, decreases in the fresh weight of the plant (Acosta-Motos et al., 2017; Salachna and Piechocki, 2016), decreases in the dry weight of the plant (Cirillo et al., 2016; Sabra et al., 2012; Beyaz and Kazankaya, 2024), in plant height (Álvarez and Sánchez-Blanco, 2014; Acosta-Motos et al., 2017), in root length (Acosta-Motos et al., 2017) and in leaf area (Cirillo et al., 2016; Acosta-Motos et al., 2017; Álvarez and Sánchez-Blanco, 2014;) have been stated by many researchers. It was emphasized that this decrease was more evident, especially in the above-ground parts (Dodd, 2005; Acosta-Motos et al., 2017).

In this study, the responses of the African violet (*Saintpaulia ionantha* L. Wendl.), whose response to salt has not yet been fully understood in the literature (Anonymous, 2024), to salt stress were investigated by watering it with different doses of salt water.

## 2. Materials and Methods

African violet (*Saintpaulia ionantha* L.), the plant used in the experiment, grows as an annual herbaceous and ornamental plant. It has been used for breeding purposes in gardening for more than a hundred years. According to the results of the studies, hybrids of this plant species are found in most parts of the world and are used as well-known ornamental plant (Kolehmainen, 2008). The plants were grown in standard pots of 10-12 cm and were purchased commercially from a company and used. The soil type used in the pot is forest soil, which is intensively found in Bingöl, Turkey. The soil was passed through a 2 mm sieve, dried in air, and put into 1.5 kg soil and used. The examined properties of the soil are texture (Bouyoucos, 1951), organic matter (Nelson and Sommers, 1982), lime (Richards, 1954), pH (in saturation), EC (U.S. Salinity Laboratory, 1954), available phosphorus (Olsen et al., 1954) and exchangeable potassium (Pratt, 1965). As a result of the soil analysis, texture is sandy and clayey, the contents of lime (1.4%) and organic matter (1.3%) are low, there is no salinity problem ( $0.1 \text{ dS m}^{-1}$ ), the soil reaction is slightly acidic (6.3), the exchangeable K content is high (308 ppm) and available P content was determined to be at high (28 ppm) level (FAO, 1990).

Pure water was used as control in the research. As salty water for irrigation, water containing different salinity conditions prepared from sodium chloride ( $\text{S1} = \text{control} = 0 \text{ dS m}^{-1}$ ,  $\text{S2} = 2.0 \text{ dS m}^{-1}$ ,  $\text{S3} = 4.0 \text{ dS m}^{-1}$ ,  $\text{S4} = 6.0 \text{ dS m}^{-1}$ ,  $\text{S5} = 8.0 \text{ dS m}^{-1}$  and  $\text{S6} = 10.0 \text{ dS m}^{-1}$ ) were used. The experiment was planned according to the randomized plot design with 4 replications. Plants were grown under laboratory conditions at the Bingöl University Agricultural Faculty Soil Science and Plant Nutrition, Bingöl, Türkiye.

The subjects investigated in the experiment were; in order to examine the development of the plant as a result of

salt applications, plant fresh weights, plant dry weights and P, K, Ca, Na, Fe, Cu, Zn, and Mn analyzes were made after 2 months in the roots and leaves. The weights of the plant were measured with a precision scale. After wet weights, in order to calculate the root and stem weights of the plants, the plants were kept in the oven to dry for 24 hours. Leaf area index was measured with a crawler leaf area measuring device. For the determination of elements in plants, the samples were burned by the wet burning method (with nitric-perchloric acid), then the Ca, Fe, Cu, Mn, and Zn contents were analyzed on the atomic absorption spectrometer, and the Na and K concentrations were determined on the flame photometer. The P contents were recorded on the spectrophotometer (Kacar, 1972). The data were statistically evaluated with the help of SPSS program.

### 3. Results and Discussion

#### 3.1. Effects of salt on some physical properties of the plant (leaf area, root fresh weight, leaf fresh weight, root dry weight and leaf dry weight)

Some changes in the leaf area, root fresh-dry weights and leaf wet-dry values of the *S. ionantha* as a result of the applied salt water solution are given in Table 1. Leaf area changes were not found to be statistically significant. It was observed that the highest value was at 2 dS m<sup>-1</sup> application and the lowest value was at 6 dS m<sup>-1</sup> application. Similar results were found in some previous studies. Salt applications reduced the leaf area in *Cotoneaster lacteus*, increased it to a certain level in *Eugenia myrtifolia*, then decreased it (Cassaniti et al., 2012) and firstly decreased it and then slightly increased it in *Callistemon citrinus* and *Viburnum titus* plants (Toscano et al., 2021).

There are studies showing that salt concentrations reduce leaf area in various ornamental plants (Cirillo et al., 2016, Acosta-Motos et al., 2017; Atal et al., 2022). Applied salt is effective in some ornamental plants such as *Salvia splendens* (Karimian et al., 2019), *Gerbera jamesonii* (Farooq et al., 2024), *Scabiosa columbaria*, *Lobelia cardinalis*, *Amelanchier canadensis*, *Cuphea hyssopifolia*, *Dikliptera suberecta*, *Pavonia lasiopetala*, *Caryopteris x clandonensis*, *Anisacanthus quadrifidus* (Wu et al., 2016), *Cyclamen hederifolium* (Akçal and Kaynaş, 2021) and *Calendula officinalis* (Bayat et al., 2012). The decrease in leaf growth due to the decrease in water in the leaves is one of the first reactions of plants to reduce salt stress (Blum, 1986), in addition, it has been stated that there are decreases in the length and weight of plant roots (Wild, 1988) and decreases in leaf area due to the decrease in the proliferation and growth of leaf cells (Atal et al., 2022).

**Table 1. Average leaf area, root fresh-dry weights, and leaf fresh-dry weights of plant obtained as a result of salt applications**

| Salt application<br>(dS m <sup>-1</sup> ) | Leaf area<br>(cm g <sup>-1</sup> ) | Root fresh<br>weight (g) | Root dry<br>weight (g) | Leaf fresh<br>weight (g) | Leaf dry<br>weight (g) |
|-------------------------------------------|------------------------------------|--------------------------|------------------------|--------------------------|------------------------|
| 0                                         | 15.71                              | 8.79a                    | 1.75a                  | 51.97                    | 2.61                   |
| 2                                         | 20.08                              | 5.32bc                   | 1.03bcd                | 46.54                    | 2.19                   |
| 4                                         | 15.58                              | 4.60bc                   | 0.81cd                 | 58.77                    | 2.43                   |
| 6                                         | 14.08                              | 6.06b                    | 1.30b                  | 47.28                    | 2.17                   |
| 8                                         | 17.52                              | 3.81c                    | 0.65d                  | 40.11                    | 2.33                   |
| 10                                        | 16.05                              | 5.14bc                   | 1.09bc                 | 52.24                    | 2.51                   |
| LSD <sub>0.05</sub>                       | n.s.                               | -1.9610**                | -0.4435**              | n.s.                     | n.s.                   |

\*n.s.: Not significant, \*\*Within a column, mean values followed by the same letter were not statistically different at the 1% level (n=4).

The change in root fresh and dry weight values of *S. ionantha* was found to be statistically significant. Classification was made accordingly, the highest wet and dry weight values were observed in the 0 dS m<sup>-1</sup> (control) salt application, and the lowest values were observed in the 8 dS m<sup>-1</sup> application. It was determined that fresh and dry root weights decreased as salt applications increased (Table 1). It has been stated in previous studies that such a situation was generally observed. It has been reported that salt causes a decrease in the root mass and function of plants (Shannon and Grieve, 1999). Salt applications on *Chrysanthemum paludosum* (Yasemin et al., 2017), *Petunia hybrida*, *Gazania splendens*, *Tagetes erecta* (Türkoğulları et al., 2013), *Plectranthus scutellarioides* (Hawrylak-Nowak et al., 2019) caused a decrease in root fresh weight. Similarly, salt is found in *Argyranthemum coronopifolium* (De Herralde et al., 1998), *C. officinalis* (Bayat et al., 2012), *Aloe vera*, *Kalanchoe blossfeldiana* and *G. splendens* (García-Caparrós et al., 2016; 2017) was found to cause a decrease in root dry weight. It has also been emphasized that salt applications reduce the dry weight of *C. lacteus*, *Cestrum aurantiacum*, *E. myrtifolia*, *Pyracantha*, *Teucrium fruticans* (Cassaniti et al.,

2009b) and *S. splendens* plants (Soundararajan et al., 2013), *Ipomoea purpurea*, *I. tricolor* (Mircea et al., 2023), *Helianthus annuus* (Ahsan et al., 2022). It has also been determined that salt reduces the fresh and dry weight of roots in some ornamental plants, e.g. *Limonium gmelinii* (halophyte) (Honfi et al., 2023), *Sesleria caerulea*, *Sorghastrum nutans* and *Koeleria glauca* (Henschke, 2017). In addition, it has been reported that salt first reduces and then increases the root dry weight of *Brassica oleracea*, but overdose reduces it again (Karagoz and Dursun, 2021). On the other hand, salt applied to *Chrysanthemum morifolium* varieties increased the root fresh-dry weights (Rahi and Singh, 2011).

As a result of the salt applications, it did not cause significant changes in the leaf fresh weight values of the *S. ionantha*. The highest wet weight was observed in the 4 dS m<sup>-1</sup> application, and the lowest weight was observed in the 8 dS m<sup>-1</sup> application. It was determined that with the increase in salt application, there was a slight decrease in leaf fresh weight and then an increase again (Table 1). Similarly, seawater was applied to *V. titus*, the biomass weight first decreased and then increased again (Toscano et al., 2021). Salt application on *T. erecta* firstly increased and then decreased the fresh bioma (Sayyed et al., 2014). It was found that salt stress negatively affected by reducing fresh leaf weight in *I. tricolor* (Mircea et al., 2023) with *Ornithogalum saundersiae* (Salachna et al., 2016) and by reducing leaf weight in rose rootstocks (Cabrera et al., 2009).

One of the physiological characteristics to salt is the decrease in plant fresh weight (Álvarez and Sánchez-Blanco, 2014; Salachna and Piechocki, 2016; Acosta-Motos et al., 2017). Salt was applied to halophytic *L. gmelinii* and fresh weights decreased (Honfi et al., 2023). Salt applications on ornamental plants, e.g., sunflower (Ahsan et al., 2022), *P. hybrida*, *G. Splendes*, *T. erecta* (Turkogullari et al., 2013), *Hibiscus rosa-sinensis*, *Mandevilla splendens* (Yu et al., 2021), *P. scutellarioides* (Hawrylak-Nowak et al., 2019), *S. caerulea*, *S. nutans*, *K. glauca* (Henschke, 2017), *C. officinalis* (Kozminska et al., 2017) and *S. splendens* (Soundararajan et al., 2013) significantly reduced the above-ground fresh weight. However, when salt water was applied to *C. morifolium* varieties, the fresh stem weights of the varieties increased (Rahi and Singh, 2011).

As seen in Table 1, it was stated that salt applications did not significantly affect the leaf dry weight of *S. ionantha*, and the lowest weight was seen in the 6 dS m<sup>-1</sup> application compared to the control. It was emphasized that salt applications reduced the dry weight of plants (Acosta-Motos et al., 2016; 2017; Cirillo et al., 2016) and halophytic *L. gmelinii* (Honfi et al., 2023).

The applications of salt were been effective in *C. lacteus* and *E. myrtifolia* (Cassaniti et al., 2009a, 2009b), *I. purpurea* and *I. tricolor* (Mircea et al., 2023), *A. coronopifolium* (De Herralde et al., 1998). ), ornamental sunflower (Ahsan et al., 2022), *S. columbaria*, *L. cardinalis*, *A. canadensis*, *C. hyssopifolia*, *D. suberecta*, *P. lasiopetala*, *Caryopteris x clandonensis*, *A. quadrifidus* and *Cestrum parqui* (Wu et al., 2016), *C. officinalis* (Bayat et al., 2012), *S. caerulea*, *S. nutans*, *K. glauca* (Henschke, 2017) and *S. splendens* (Soundararajan et al., 2013) was reported to reduce the dry weight of the above-ground parts. It was determined that salt applications similarly caused a decrease in dry weights on some ornamental plants, e.g., *A. vera*, *K. blossfeldiana*, *G. splendens* (García-Caparrós et al., 2016; 2017), *C. lacteus*, *C. aurantiacum*, *E. myrtifolia* and *Pyracantha* (Cassaniti et al., 2009a, 2009b). However, in *C. morifolium* varieties, salt increased the stem dry weight (Rahi and Singh, 2011).

### 3.2. Effects of salt on some macronutrient element contents (P, K, Ca and Na) in plant roots

The changes in the values of some macro elements (P, K, Ca and Na) in the root of *S. ionantha* with salt application are given in Table 2. The effects of salt applications on phosphorus, potassium and calcium contents were not statistically significant, but they significantly affected sodium content of root of *S. ionantha*.

Phosphorus values in the root of *S. ionantha* with salt application were found to be between 0.013% and 0.014%. From previous studies, it was reported that P content decreased as a result of salt applications for example, in *Antirrhinum majus* (Carter and Grieve, 2008), in *Chamaerops humilis* and *Washingtonia robusta* (Simón et al., 2010), in *Diantus caryophyllus* (Navarro et al., 2012), in *Cordyline fruticosa* (Plaza et al., 2012a; 2012b), in *Nepeta x faassenii* and *Phlox subulata* (Eom et al., 2007) and *C. morifolium* (Rahi and Singh, 2011). In addition, it was stated that salt applications increased the P content in *Alchemilla mollis*, but did not cause any change in *Sedum acre*, *Solidago cutleri* and *Thymus praecox* (Eom et al., 2007). It can be said that these different results are due to plant type and application differences.



**Table 2. Average of phosphorus, potassium, calcium, and sodium in the root obtained as a result of salt applications**

| Salt application<br>(dS m <sup>-1</sup> ) | Phosphorus<br>(%) | Potassium<br>(%) | Calcium<br>(mg kg <sup>-1</sup> ) | Sodium<br>(mg kg <sup>-1</sup> ) |
|-------------------------------------------|-------------------|------------------|-----------------------------------|----------------------------------|
| 0                                         | 0.013             | 1.93             | 11.60                             | 430.0b                           |
| 2                                         | 0.014             | 1.25             | 11.68                             | 360.0b                           |
| 4                                         | 0.014             | 2.24             | 11.71                             | 635.0a                           |
| 6                                         | 0.013             | 1.75             | 11.50                             | 437.5b                           |
| 8                                         | 0.014             | 1.78             | 11.92                             | 450.0b                           |
| 10                                        | 0.014             | 1.72             | 11.79                             | 680.0a                           |
| LSD <sub>0.05</sub>                       | n.s.              | n.s.             | n.s.                              | -176.60**                        |

n.s.: Not significant, \*\*Within a column, mean values followed by the same letter were not statistically different at the 1% level (n=4).

It was observed that salt applications did not significantly affect the potassium values in the roots of *S. ionantha*, the highest value was at 4 dS m<sup>-1</sup> and the lowest was at 2 dS m<sup>-1</sup> application. There are previous studies that salt applications reduced K content, e.g., in *A. majus* (Carter and Grieve, 2008), *Arbutus unedo* (Navarro et al., 2008), *C. humilis* and *W. robusta* (Simón et al., 2010), *Cichorium spinosum* (Ntatsi et al., 2017), *D. caryophyllus* (Navarro et al., 2012), *Escallonia exoniensis*, *Raphiolepis indica* and *Buxus microphylla* (Valdez-Aguilar et al., 2011), *Matthiola incana* (Grieve et al., 2006), *C. fruticosa* (Plaza et al., 2012a; 2012b), *Osteospermum hybrida* (Valdés et al., 2015), *Rosa hybrida* (Niu et al., 2013), *Tagetes erecta* (Koksall et al., 2014; 2016), *T. praecox* (Eom et al., 2007), *Gaura lindheimeri* and *Westringia fruticosa* (Ferrante et al., 2011), *Quercus robur* and *Tilia cordata* (Marosz and Nowak, 2008). In addition, it has been stated that salt applications do not cause changes in K content of plants such as *Nepeta x faassenii*, *P. subulata*, *S. cutleri* (Eom et al., 2007), *H. rosa sinensis*, *Juniperus chilensis* (Valdez-Aguilar et al., 2011), *C. citrinus*, *Jasminum sambac* (Ferrante et al., 2011), *Chaenomeles speciosa*, *Hydrangea macrophylla*, *Parthenocissus quinquefolia* (Liu et al., 2017), *Acer negundo* and *A. platanoides* (Marosz and Nowak, 2008). Despite this, salt applications were reported to increase K content in plants, such as in *A. mollis*, *S. acre* (Eom et al., 2007), *C. morifolium* (Rahi and Singh, 2011), *Acacia cultriformis*, *Carissa edulis* (Ferrente et al., 2011), *C. speciosa*, *Diervilla rivularis* varieties, *Forsythia x intermedia* and *Hibiscus syriacus* (Liu et al., 2017). It can be said that the different results caused from varietie of plants and diversity of applications.

With salt applications, the calcium values in the roots of *S. ionantha* were highest at 8 dS m<sup>-1</sup> application and lowest at 6 dS m<sup>-1</sup> application. It has been observed that salt applications do not significantly affect calcium values. Similarly, in *Nepeta x faassenii*, *S. acre*, *S. cutleri* and *T. praecox* (Eom et al., 2007), *A. cultriformis*, *C. citrinus* and *C. edulis microphylla* (Ferrante et al., 2011) and *A. negundo* (Marosz and Nowak, 2008) found that calcium content did not change significantly with salt applications. On the other hand, root Ca contents decreased with salt applications to ornamental sunflower (Ahsan et al., 2022), *G. lindheimeri* and *W. fruticosa* (Ferrante et al., 2011), *A. unedo* (Navarro et al., 2008), *W. robusta* (Simón et al., 2010), *D. caryophyllus* (Navarro et al., 2012), *M. incana* (Grieve et al., 2006), *R. hybrida* (Niu et al., 2013), *G. lindheimeri* and *W. fruticosa* (Ferrante et al., 2011) and *A. platanoides* (Marosz and Nowak, 2008). In contrast, calcium contents increased in some plants for example, in *J. sambac* (Ferrante et al., 2011), in *C. morifolium* cultivars (Rahi and Singh, 2011), in *T. erecta* (Koksall et al., 2014; 2016), in *A. mollis* and *P. subulata* (Eom et al., 2007), in *C. speciosa*, *C. speciosa*, *D. rivularis* varieties, *Forsythia x intermedia*, *H. syriacus*, *H. macrophylla* varieties and *P. quinquefolia* (Liu et al., 2017) and *Q. robur* (Marosz and Nowak, 2008) with salt treatments.

With salt application, significant changes were found in the sodium values in the root of *S. ionantha*. As the salt content increased, the amount of sodium in the root also increased and the highest value was observed at 10 dS m<sup>-1</sup> and the lowest at 2 dS m<sup>-1</sup>. A similar situation has been observed in previous studies. Salt applications were increased Na concentrations in the plant root, e.g., in different rose rootstocks (Cabrera et al., 2009), ornamental sunflower (*H. annuus*) (Ahsan et al., 2022), *A. mollis*, *Nepeta x faassenii*, *S. acre*, *P. subulata*, *S. cutleri* and *T. praecox* (Eom et al., 2007), *C. morifolium* varieties (Rahi and Singh, 2011), *Narcissus sp.*, *Amaryllidaceae* (Veatch-Blohm et al., 2014), *S. caerulea*, *S. nutans* and *K. glauca* (Henschke, 2017) and *A. vera*, *K. Blossfeldiana* and *G. splendens* (García-Caparrós et al., 2016; 2017).



In this study, excess sodium ion in the medium did not cause a significant change in calcium and potassium ions in the roots of *S. ionantha*. Lewitt (1980) stated that in some salt-resistant or tolerant plants, potassium and calcium are taken up more as the sodium in the environment increases, and the ratios of potassium and calcium increase along with sodium. In the light of this information, it can be stated that *S. ionantha* has low salt tolerance and poor tolerance to a salty environment.

### 3.3. Effects of salt on some micronutrient contents (Mn, Zn, Cu and Fe) in plant roots

The changes in the contents of some microelements (Mn, Zn, Cu and Fe) in the root of *S. ionantha* due to salt applications were found to be statistically significant (Table 3). The application with the highest manganese content was 8 dS m<sup>-1</sup> and the lowest application was 10 dS m<sup>-1</sup>. Accordingly, the Mn content first decreased, then increased, and then decreased again. Similarly, it was reported that salt applications increased the Mn content in the root in *A. mollis* (Eom et al., 2007).

Table 3. Average Mn, Zn, Cu, and Fe in the plant root of *S. ionantha* L.

| Salt application<br>(dS m <sup>-1</sup> ) | Manganese<br>(mg kg <sup>-1</sup> ) | Zinc<br>(mg kg <sup>-1</sup> ) | Copper<br>(mg kg <sup>-1</sup> ) | Iron<br>(mg kg <sup>-1</sup> ) |
|-------------------------------------------|-------------------------------------|--------------------------------|----------------------------------|--------------------------------|
| 0                                         | 82.55abc                            | 61.00b                         | 142.75b                          | 3.43b                          |
| 2                                         | 68.60bc                             | 77.30a                         | 142.90b                          | 3.38b                          |
| 4                                         | 72.05bc                             | 55.45bc                        | 153.20a                          | 3.75b                          |
| 6                                         | 100.00ab                            | 55.35bc                        | 152.00ab                         | 4.70b                          |
| 8                                         | 108.75a                             | 66.45ab                        | 154.45a                          | 6.19a                          |
| 10                                        | 53.85c                              | 39.80c                         | 157.75a                          | 3.34b                          |
| LSD <sub>0.05</sub>                       | -33.100**                           | -17.416**                      | -9.154**                         | -1.428**                       |

\*\*Within a column, mean values followed by the same letter were not statistically different at the 1% level (n=4).

Zinc and iron rates in the root of *S. ionantha* with salt application first increased and then decreased, and the lowest values were observed at 10 dS m<sup>-1</sup>. It was determined that the applications with the highest copper content in the root were 4, 8, and 10 dS m<sup>-1</sup>, and the lowest applications were 0 dS m<sup>-1</sup> and 2 dS m<sup>-1</sup>. It was observed that as salt applications increased, Mn, Zn, and Fe contents in the root increased up to 8 dS.m<sup>-1</sup> application, while Cu content increased up to 10 dS.m<sup>-1</sup> application. Previous studies have also emphasized that excessive salt reduces the Zn and Fe content in corn and beans (Malkoç and Aydın, 2003), and the Fe content in *O. saundersiae* (Salachna et al., 2016).

### 3.4. Effects of salt on some macronutrient contents (P, Ca, K and Na) in the leaves of *S. ionantha* L.

With the salt applications, changes in the calcium and sodium contents of some macro element contents in the leaves of *S. ionantha* were statistically found to be significant, and an increase in the Ca, K and Na contents, except P, was observed in the Table 4.

Table 4. Average P, Ca, K, and Na in the plant leaves of *S. ionantha* L.

| Salt application<br>(dS m <sup>-1</sup> ) | Phosphorus<br>(%) | Calcium<br>(mg kg <sup>-1</sup> ) | Potassium<br>(mg kg <sup>-1</sup> ) | Sodium<br>(mg kg <sup>-1</sup> ) |
|-------------------------------------------|-------------------|-----------------------------------|-------------------------------------|----------------------------------|
| 0                                         | 0.010             | 11.72d                            | 10.90                               | 3.79c                            |
| 2                                         | 0.011             | 13.12cd                           | 10.67                               | 4.13c                            |
| 4                                         | 0.010             | 14.79bc                           | 10.75                               | 11.34b                           |
| 6                                         | 0.010             | 17.01ab                           | 11.13                               | 12.84b                           |
| 8                                         | 0.010             | 18.31a                            | 12.12                               | 16.01a                           |
| 10                                        | 0.010             | 16.41ab                           | 12.44                               | 17.48a                           |
| LSD <sub>0.05</sub>                       | n.s.              | -2.2343**                         | n.s.                                | -2.592**                         |

n.s.: Not significant, \*\*Within a column, mean values followed by the same letter were not statistically different at the 1% level (n=4).

Similarly, salt applications were reported that *Potentilla fruticosa* “Longacre” (Marosz, 2004), *S. acre*, *S. cutleri* and *T. praecox* (Eom et al., 2007), *A. negundo*, *A. platanioides*, *Q. robur* and *T. cordata* (Marosz and Nowak, 2008) of the P contents in leaves were determined to not change. In contrast, salt applications to plants, e.g., *S. caerulea*, *K. glauca* (Henschke, 2017), *A. majus* (Carter and Grieve, 2008), *C. humilis*, *W. robusta* (Simón et al.,

2010), *D. caryophyllus* (Navarro et al., 2012), *C. fruticosa* (Plaza et al., 2012a; 2012b), *Nepeta x faassenii*, *P. subulata* (Eom et al., 2007) and *C. morifolium* (Rahi and Singh, 2011), was determined that reduced leaf P content. However, it has also been reported that leaf P content of *Cotoneaster*, *Spiraea* (Marosz, 2004) and *A. mollis* (Eom et al., 2007) increased with salt applications.

It was observed that the highest calcium rate in the leaves of *S. ionantha* was 8 dS m<sup>-1</sup>, and the lowest application was 2 dS m<sup>-1</sup>. It has also been stated in previous studies that an increase in Ca content of leaves was detected with salt applications to different plants, e.g. *S. caerulea*, *S. nutans*, *K. glauca* (Henschke, 2017), *Spiraea*, *Cotoneaster horizontalis* (Marosz, 2004), *Rose chinensis* (Li et al., 2016), *Plectranthus ciliatus* (Salachna et al., 2016), *T. erecta* (Koksall et al., 2014; 2016), *A. mollis*, *S. acre* (Eom et al., 2007), *C. morifolium* (Rahi and Singh, 2011), *C. speciosa* varieties, *D. rivularis* varieties, *Forsythia x intermedia*, *H. syriacus*, *H. macrophylla* varieties, *P. quinquefolia* (Liu et al., 2017) and *Q. robur* (Marosz and Nowak, 2008).

Despite this, it has been emphasized that salt reduces the amount of leaf calcium (Salachna et al., 2016; Navarro et al., 2008; 2012; Simón et al., 2010; Grieve et al., 2006; Niu et al., 2013; Ferrante et al., 2011; Nowak, 2008; Marosz, 2004), and sometimes it has been reported that it does not cause any change significantly (Eom et al., 2007; Ferrante et al., 2011; Marosz and Nowak, 2008).

There was no significant increase in the potassium values in the leaves as a result of the salt applied to *S. ionantha*. In parallel with our study, it was found that the salt applications did not significantly change the K content in plant leaves, e.g., *I. purpurea* (Mircea et al., 2023), *P. fruticosa*, *C. horizontalis* (Marosz, 2004) and *C. officinalis* (Kozminska et al., 2017). Differently from these results, in other plants, e.g., *I. tricolor* (Mircea et al., 2023), *Rose chinensis* (Li et al., 2016), *A. cultriformis*, *C. edulis microphylla* (Ferrante et al. 2011), *O. saundersiae* (Salachna et al., 2016), *S. acre* and *A. mollis* (Eom et al., 2007), and *C. morifolium* varieties (Rahi and Singh, 2011), it was reported that leaf K content increased. In the different studies have stated that salt reduces the K content in the leaf (Hu and Schmidhalter, 1997; Biçer, 2016; Karakas et al., 2021; Hooks and Niu, 2019; Salachna et al., 2016; El-Serafy et al., 2021; Ahsan et al., 2022; Ferrante et al., 2011; Marosz, 2004; Eom et al., 2007; Henschke, 2017).

With the application of salt, there was a significant increase in the amount of sodium in the leaves of *S. ionantha*, the highest rate was observed at 10 dS m<sup>-1</sup> and the lowest value was observed at 0 dS m<sup>-1</sup>. Similar results were encountered in studies conducted on different plants (Mircea et al., 2023; Salachna et al., 2016; Li et al., 2016; El-Serafy et al., 2021; Cabrera et al., 2009; Ahsan et al., 2022; Ferrante et al., 2011; Honfi et al., 2023; Marosz, 2004; Eom et al., 2007; Rahi and Singh, 2011; Henschke, 2017; Kozminska et al., 2017).

This situation, which occurs with the increase in sodium, which is a nutrient element for the *S. ionantha* plant, has a positive reflection on other nutritional elements, especially potassium and calcium, and the intake of potassium and calcium along with sodium has increased up to a certain level. These results are consistent with previous studies reporting that sufficient amounts of sodium or salt supplied or present in the environment increase potassium and calcium uptake in some plants (Eom et al., 2007; Rahi and Singh, 2011; Liu et al., 2017).

### 3.5. Effects of salt on some micronutrient contents (Mn, Zn, Cu, and Fe) in the leaves of *S. ionantha* L.

The Mn, Zn, Cu and Fe elements examined in the leaves of *S. ionantha* plants increased significantly with salt applications (Table 5).

It was similarly reported that salt applied to *A. mollis* increased its Mn content (Eom et al., 2007). It has been reported that Mn and Zn nutrients in wheat leaves are not significantly affected by salinity (Hu et al., 2000; Hu and Schmidhalter, 2001).

It was determined that the copper values in the leaves of *S. ionantha* increased up to certain levels (4, 6, and 8 dS m<sup>-1</sup>) and then decreased. A similar result was reported by Malkoç and Aydın (2003) in different plant.

It was observed that salt applications increased the iron content in the leaves of *S. ionantha* plant, the highest application was obtained from 8 dS m<sup>-1</sup> application and the lowest application was obtained from 2 dS m<sup>-1</sup> application. It was reported that nutrient Fe in wheat leaves was largely unaffected by salinity (Hu et al., 2000; Hu and Schmidhalter, 2001).

**Table 5. Average Mn, Zn, Cu, and Fe in the plant leaves of *S. ionantha* L.**

| Salt application<br>(dS m <sup>-1</sup> ) | Manganese<br>(mg kg <sup>-1</sup> ) | Zinc<br>(mg kg <sup>-1</sup> ) | Copper<br>(mg kg <sup>-1</sup> ) | Iron<br>(mg kg <sup>-1</sup> ) |
|-------------------------------------------|-------------------------------------|--------------------------------|----------------------------------|--------------------------------|
| 0                                         | 75.20c                              | 89.20b                         | 152.25d                          | 2.01b                          |
| 2                                         | 49.55c                              | 81.10b                         | 151.65d                          | 1.79b                          |
| 4                                         | 181.80b                             | 163.90a                        | 172.70a                          | 2.58b                          |
| 6                                         | 27.50a                              | 172.40a                        | 166.75ab                         | 5.61a                          |
| 8                                         | 283.95a                             | 161.80a                        | 160.80bc                         | 5.63a                          |
| 10                                        | 220.75ab                            | 165.45a                        | 157.45cd                         | 3.30ab                         |
| LSD <sub>0.05</sub>                       | -67.44**                            | -40.528**                      | -6.739**                         | -2.4532*                       |

\* Within a column, mean values followed by the same letter were not statistically different at the 5% level (n=4),

\*\*Within a column, mean values followed by the same letter were not statistically different at the 1% level (n=4).

#### 4. Conclusions

According to the results, it can be said that salt, brine, or NaCl applications up to a certain level have a positive effect on the plant development and nutritional content of *S. ionantha*. However, it is also a fact that plants exposed to salt applications above a certain level or in excessive doses experience physiological regressions and problems in nutrient uptake. According to the results of the research, it was observed that salinity after a certain level negatively affected some nutritional physical properties and nutrient uptake of *S. ionantha* plant. Therefore, it should be taken into consideration that excessive salt content in the water in which plants are fed may cause some adverse conditions. It has also been predicted that the uptake of some elements decreases due to the effect of osmotic pressure created by salt. It has been observed that some elements are taken up in large amounts by the roots due to the effect of excess salt. Again, it has been observed that some physiological properties of the plant are negatively affected due to salinity. In order to avoid the problems mentioned above, it should be taken into consideration that optimum amounts of Na can be given to many other plants, as in the *S. ionantha* plant discussed in this study, but excessive salt or irrigation with water with high salt content may adversely affect the physiological and nutritional status.

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#### Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

#### Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

#### Authorship Contribution Statement

Concept: Demirkıran, A.R., Polat, G.; Design: Demirkıran, A.R., Polat, G.; Data Collection or Processing: Demirkıran, A.R., Polat, G.; Statistical Analyses: Demirkıran, A.R.; Literature Search: Demirkıran, A.R.; Writing, Review and Editing: Demirkıran, A.R.

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## Optimizing Sunflower Yield Under Water Constraints: A Comparative Analysis of Irrigation Strategies, Seed Varieties, and Simulation Models

Su Kısıtı Koşullarında Ayçiçeği Veriminin Optimizasyonu: Sulama Stratejileri, Tohum Çeşitleri ve Simülasyon Modellerinin Karşılaştırmalı Analizi

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### Abstract

This study explored the impact of increasing water restrictions, driven by climate change, on sunflower yield and assessed the adaptability of different seed varieties to these challenging conditions. Three irrigation strategies were applied: S0 (no irrigation), S1 (semi-irrigation), and S2 (full irrigation). Two sunflower cultivars, Sanay and Pioneer, were tested to evaluate how irrigation and seed variety influence key parameters such as leaf area index (LAI), normalized difference vegetation index (NDVI), plant height, and yield. The results indicated that the Pioneer variety generally exhibited higher LAI and yield values compared to Sanay. The maximum LAI value of 4.43 was observed in July under full irrigation (S2). NDVI results further supported these findings, showing that fully irrigated Pioneer plants had higher photosynthetic activity, indicating better adaptation to water stress. While Sanay produced taller plants and relatively high biomass even without irrigation (S0), Pioneer achieved superior yield performance under optimal water conditions. Both cultivars recorded their highest yields under the S2 treatment, highlighting the significance of effective water management for sunflower production. To complement the experimental data, yield predictions were performed using three crop simulation models: AquaCrop, DSSAT, and WOFOST. Among these, AquaCrop provided the most accurate predictions, especially under full irrigation, showing strong alignment with observed yield values. However, the variability observed in model predictions emphasizes the need for careful assessment of these tools across different environmental conditions. In conclusion, selecting appropriate seed varieties and developing optimized irrigation strategies are critical for maintaining agricultural sustainability under water-limited conditions driven by climate change. The accurate simulation of crop yields under different irrigation regimes can further support decision-making processes, but variability in model outputs highlights the importance of model validation based on environmental factors.

**Keywords:** Sunflower, Deficit irrigation, Seed varieties, Simulation models, Climate change, Water management, Yield prediction

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## Öz

Bu çalışma, iklim değişikliğinin neden olduğu artan su kısıtlamalarının ayçiçeği verimi üzerindeki etkisini ve farklı tohum çeşitlerinin bu zorlayıcı koşullara uyumunu incelemiştir. Üç sulama stratejisi uygulanmıştır: S0 (sulamadan), S1 (kısmi sulama) ve S2 (tam sulama). Ayrıca, iki ayçiçeği çeşidi olan Sanay ve Pioneer kullanılarak sulama ve tohum çeşitlerinin yaprak alan indeksi (LAI), normalize edilmiş fark bitki indeksi (NDVI), bitki boyu ve verim gibi temel parametreler üzerindeki etkileri değerlendirilmiştir. Sonuçlar, Pioneer çeşidinin genel olarak Sanay'a kıyasla daha yüksek LAI ve verim değerleri sergilediğini ortaya koymuştur. En yüksek LAI değeri olan 4.43, Temmuz ayında tam sulama (S2) altında kaydedilmiştir. NDVI sonuçları, tam sulanan Pioneer bitkilerinin daha yüksek fotosentetik aktivite gösterdiğini ve su stresine daha iyi uyum sağladığını göstermektedir. Sanay çeşidi ise sulama olmaksızın (S0) bile daha uzun bitkiler ve nispeten yüksek biyokütle üretimi ile dikkat çekmiştir. Ancak, Pioneer çeşidi optimum su koşulları altında en yüksek verim performansını sağlamıştır. Her iki çeşit de en yüksek verim değerlerini S2 sulama stratejisinde elde etmiş olup, etkili su yönetiminin ayçiçeği üretimi için önemini vurgulamaktadır. Deneysel verileri desteklemek amacıyla AquaCrop, DSSAT ve WOFOST olmak üzere üç farklı ürün simülasyon modeli kullanılarak verim tahminleri yapılmıştır. Bu modeller arasında, AquaCrop en doğru tahminleri sağlamış ve özellikle tam sulama koşullarında gözlemlenen verim değerleri ile güçlü bir uyum göstermiştir. Ancak, modeller arasında gözlemlenen tahmin farklılıkları, bu araçların farklı çevresel koşullara göre dikkatle değerlendirilmesi gerektiğini ortaya koymaktadır. Sonuç olarak, uygun tohum çeşitlerinin seçimi ve optimize edilmiş sulama stratejilerinin geliştirilmesi, iklim değişikliğinin neden olduğu su kıtlığı koşullarında tarımsal sürdürülebilirliğin sağlanması açısından kritik öneme sahiptir. Farklı sulama rejimleri altında ürün verimlerinin doğru bir şekilde simüle edilmesi, karar verme süreçlerini destekleyebilir; ancak model çıktılarındaki değişkenlik, modellerin çevresel faktörler göz önüne alınarak doğrulanmasının gerekliliğini göstermektedir.

**Anahtar Kelimeler:** Ayçiçeği, Kısıtlı sulama, Tohum çeşitleri, Simülasyon modelleri, İklim değişikliği, Su yönetimi, Verim tahmini

## 1. Introduction

Water is one of the most critical factors limiting agricultural production globally (Hussain et al., 2018; Unger, 1990; Farooq et al., 2011). In regions with insufficient rainfall, water stress hampers plant growth and yield by slowing down cell division and expansion (Sadras et al., 2016). This results in the loss of turgor as water availability in plant cells decreases (Tezara et al., 2002; Osakabe et al., 2014). Drought, one of the most significant stress factors affecting plant growth and yield, happens when soil lacks sufficient moisture to meet the water demands of plants. The severity and duration of drought affect various physiological processes (Hsiao, 2009; Begna, 2020). Climate change exacerbates water scarcity, increasing pressure on agricultural production (Debaeke et al., 2017; Fahad et al., 2017). In response, developing effective irrigation strategies that enhance water use efficiency is critical for global food security (Pereira et al., 2002; Blum, 2009).

Sunflower (*Helianthus annuus* L.) is an essential oilseed crop cultivated in semi-arid regions like the Thrace region of Turkey (Fulda et al., 2011; Önemli, 2005). Agricultural production in these areas primarily relies on rainfall, but increasing water constraints make this practice unsustainable (Kaya et al., 2016). Sunflower is sensitive to water stress, and drought can significantly reduce its yield (Connor and Hall, 1997; Sarazin et al., 2017). Hence, selecting drought-tolerant seed varieties and determining appropriate irrigation strategies are crucial for sustainable agricultural production in such regions (Hussain et al., 2017).

Recently, plant growth models have become essential for assessing agricultural production under water constraints (Todorovic et al., 2009). These models predict the performance of different irrigation strategies and seed varieties to optimize agricultural practices (Castañeda-Vera et al., 2015). They provide a quantitative analysis of how stresses impact plant growth and yield, helping to determine optimal management strategies under drought (Razzaghi et al., 2017; Ran et al., 2020). Models like AquaCrop, DSSAT, and WOFOST have been developed to predict crop yields under water constraints and calibrated for various regions (Steduto et al., 2009; Raes et al., 2009; Abedinpour, 2021; Dewenam et al. 2021; Gürkan, 2023). Although numerous studies have examined the effects of water stress on sunflower yield, few have integrated irrigation strategies with crop growth models like AquaCrop, DSSAT, and WOFOST to evaluate their accuracy in predicting yields under water constraints. This study seeks to fill this gap by combining these models with field data to assess their reliability and optimize water management decisions in sunflower production.

This research aims to assess the effectiveness of different irrigation strategies and sunflower varieties in the Thrace region, examining the accuracy of yield predictions provided by plant growth models. By incorporating the AquaCrop, DSSAT, and WOFOST models, this study provides a comprehensive comparison of their accuracy in predicting crop yield under different irrigation strategies, offering insights for more informed water management practices. The findings will contribute to identifying strategies that can be used under water constraints and how they can be applied in the context of climate change.

## 2. Materials and Methods

### 2.1. Trial area and material

The experiment was carried out in 2019 at the Kırklareli Atatürk Soil, Water, and Agricultural Meteorology Research Institute, situated at a latitude of 41°42'11" N and a longitude of 27°12'29" E. The region's average yearly temperature is 13.3 °C, with an average annual precipitation of 583,7 mm (Anonymous, 2022a). Approximately 64% of the region's land is agricultural, with about 62% of it predominantly rainfed and mainly used for wheat and sunflower cultivation (Anonymous, 2022b). Some physical and chemical properties of the experimental field soil are given in Table 1. The monthly climate data (Figure 1) showing relatively stable temperature values throughout the period. In this study, Pioneer and Sanay sunflower varieties, commonly used in the region, were chosen as the plant material. Water used for irrigation was taken from a deep well within the institute's land. The water had the following values: pH  $7.26 \pm 0.03$ ; EC  $1.12 \pm 0.04$  dS m<sup>-1</sup>; NH<sub>4</sub><sup>+</sup>-N  $0.12 \pm 0.001$  mg kg<sup>-1</sup>; and NO<sub>3</sub><sup>-</sup>-N  $0.60 \pm 0.015$  mg kg<sup>-1</sup>.

The drip irrigation system used in the study consisted of control unit, hydrocyclone, screen filter, pressure regulator, manometers for irrigation water and pressure measurements. In the irrigation system; 50 mm outer diameter hard PE pipes were used for the main pipeline, 40 mm outer diameter hard PE pipes for manifold pipelines and 16 mm diameter PE pipes laid in each plant row with 2 L/h in-line drippers whose spacing and flow rate were determined according to the infiltration rate of the soil (15.2 mm/h).

The pioneer variety used in the research is a variety with a high yield potential both in arid conditions and in rainy and irrigated conditions, with a high oil content and a wide cultivation rate in the region. Sanay variety is an early variety, also suitable for late planting and second crop cultivation. It has no soil selectivity and high adaptability. It has high drought resistance.

This experiment provides a novel approach by combining field data with three distinct crop simulation models to assess their accuracy in predicting sunflower yield under different irrigation strategies, addressing a critical gap in current literature. To estimate sunflower yield, AquaCrop, DSSAT, and WOFOST simulation models were utilized in the study.

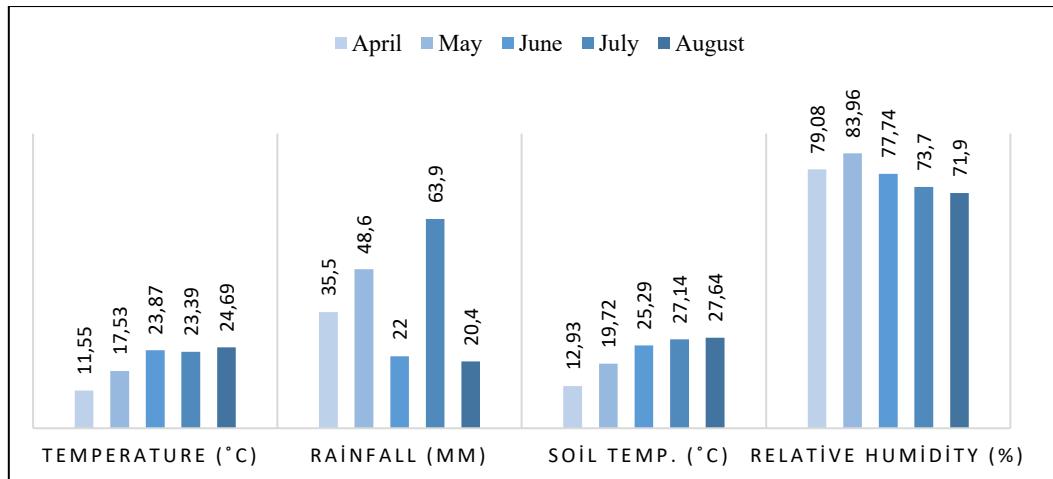


**Figure 1. Monthly temperature and rainfall averages during the plant growth period**

**Table 1. Physical and chemical analysis results of the experiment site soil**

|                          | 0-30 (cm)     | 30-60 (cm)    | 60-90 (cm)    |
|--------------------------|---------------|---------------|---------------|
| pH                       | 7.56 ± 0.10   | 7.57 ± 0.10   | 7.52 ± 0.10   |
| Organic matter (%)       | 1.22 ± 0.08   | 0.85 ± 0.07   | 0.66 ± 0.07   |
| Field capacity (%)       | 22.53 ± 1.15  | 23.37 ± 1.19  | 25.50 ± 1.20  |
| Wilting point (%)        | 10.42 ± 0.60  | 10.31 ± 0.60  | 12.82 ± 0.68  |
| P (kg ha <sup>-1</sup> ) | 20.14 ± 0.88  | 20.01 ± 0.88  | 21.25 ± 0.90  |
| K (kg ha <sup>-1</sup> ) | 210.08 ± 2.97 | 229.04 ± 3.00 | 221.47 ± 3.00 |
| Texture                  | Sandy Loam    |               |               |

\* Data are presented as mean ± standard error.

## 2.2. Experiment set up and agricultural applications

This study was conducted at Kırklareli Atatürk Soil, Water, and Agricultural Meteorology Research Institute in 2019. The experiment was established in a strip plots experimental design with 3 replications and 2 different sunflower seeds (Sanay and Pioneer) and 3 different irrigation subjects (S2, S1, S0) were applied. Trial plots were 20 × 15 m in size and 6 separate plots were formed for each subject. Irrigation subjects were determined as S2, which represents the 15-day irrigation interval in which all of the soil moisture was increased to the field capacity, S1, in which half of this amount of irrigation water was applied, and S0, which is the control subject based on rainfall. Irrigations were carried out using the drip irrigation method, and the amount of irrigation water was monitored by water clocks placed at the beginning of the plots. In addition, the flow rates of drippers were measured to calculate the irrigation time. The total amount of irrigation water applied to the subjects during the experiment is given in Table 2.

Sowing was carried out on April 19, 2019, and 10 kg ha<sup>-1</sup> DAP fertilizer was applied with 300 grams of seed per decare. The second fertilization was done on May 27, 2019, with 100 kg ha<sup>-1</sup> urea fertilizer application. For weed control, 1250 g ha<sup>-1</sup> 40 g L<sup>-1</sup> imazamox active ingredient herbicide was applied on May 20, 2019.

Plant growth parameters such as plant height, crown width, leaf area index (LAI), and Normalized Difference Vegetation Index (NDVI) were measured on May 28, June 14, July 9, and August 6. Leaf area index measurements were made with an LI-COR brand LAI 2200C model device and NDVI measurements were made with a Trimble

GreenSeeker portable model with 5 replications in each replicate. Biomass was calculated with 5 randomly selected plants in each replicate, and at harvest, biomass and grain yield values were determined on 15 randomly selected plants to best represent each plot. Plant developmental stages (*Table 3*) were determined by phenological observations in the experimental plots.

The LAI and NDVI measurements were used to validate the accuracy of simulation models in predicting plant growth and water use efficiency under different irrigation strategies.

**Table 2. Amount of water applied to irrigation subjects (mm)**

| Date       | S0 | S1 | S2 |
|------------|----|----|----|
| 14.05.2019 | 0  | 50 | 50 |
| 31.05.2019 | 0  | 12 | 25 |
| 04.06.2019 | 0  | 12 | 25 |
| 14.06.2019 | 0  | 20 | 40 |
| 28.06.2019 | 0  | 40 | 80 |
| 12.07.2019 | 0  | 35 | 70 |

**Table 3. Phenological developmental stages of sunflower varieties**

| Phenological Period   | Sanay      | Pioneer    |
|-----------------------|------------|------------|
| Sowing                | 19.04.2019 | 19.04.2019 |
| Plant emergence       | 01.05.2019 | 01.05.2019 |
| Leafing               | 22.05.2019 | 22.05.2019 |
| Flower head formation | 17.06.2019 | 22.06.2019 |
| Flowering             | 29.06.2019 | 03.07.2019 |
| Maturation            | 15.07.2019 | 31.07.2019 |
| Harvest               | 09.09.2019 | 09.09.2019 |

### 2.3. Analysis methods

Soil pH and EC values were determined in a saturation paste (Soil Survey Lab. Staff, 1975). Organic matter content was measured using the modified Walkley-Black method (Jackson, 1979), while lime (% CaCO<sub>3</sub>) content was assessed by the Scheibler calcimeter method (Loeppert and Suarez, 1996). Available phosphorus was determined by the Olsen method (Sims, 2000), and exchangeable potassium was extracted with 1 N ammonium acetate (Soil Survey Lab. Staff, 1975). Soil texture was analyzed using the hydrometer method (Gee and Bauder, 1986). Field capacity was determined at 1/3 atmosphere and wilting point at 15 atmospheres using the pressure plate method (Klute, 1986). Bulk density was calculated by drying undisturbed soil samples, collected with steel cylinders of 100 cm<sup>3</sup> volume, at 105°C for 24 hours in an oven, and dividing the oven-dry soil weight by the total volume of the cylinder (Blake and Hartge, 1986).

NDVI measurements were conducted using a portable GreenSeeker device (Trimble) at regular intervals during the growing season, with values calculated using the following formula (Rouse et al., 1974):

$$NDVI = (NIR + Red) / (NIR - Red) \quad (Eq. 1)$$

NDVI=Normalized difference vegetation index, NIR= light reflected in the near-infrared spectrum Red= light reflected in the red range of the spectrum.

LAI was determined using the LAI-2200C Plant Canopy Analyzer (LI-COR), which measures the leaf area per unit ground area by analyzing light transmission through the canopy. Measurements were taken at five points within each replication to ensure accuracy (Welles and Norman, 1991).

Three crop simulation models (AquaCrop, DSSAT, and WOFOST) were utilized to estimate sunflower yield under different irrigation scenarios. Each model was employed to simulate crop growth, water use, and yield, and their methodologies are summarized below. In the three growth models used, some of the data in the models were used, while soil, plant, climate and irrigation data were actual data obtained from field experiments.

AquaCrop, developed by the Food and Agriculture Organization (FAO), is a model designed to simulate the yield response of herbaceous crops to water (Raes et al., 2009). The model is particularly suited to conditions where water



is a key limiting factor. AquaCrop considers climate, soil, crop, irrigation, and initial soil water conditions as input parameters. The model separates soil evaporation from crop transpiration and uses a water productivity parameter (WP) to estimate biomass production directly from crop transpiration (Steduto et al., 2009). Yield (Y) is then derived from biomass (B) using the harvest index (HI) equation:

$$Y = HI * B \quad (\text{Eq. 2})$$

This model is widely used for its ability to simulate the impact of different irrigation strategies on crop yield, making it an essential tool for water management in agriculture (Hsiao et al., 2009).

The Decision Support System for Agrotechnology Transfer (DSSAT) is a comprehensive crop simulation model that integrates soil, plant, and weather data to predict crop growth and yield (Jones et al., 2003). DSSAT's modular design allows for the simulation of various crops under different management practices. In this study, the CROPGRO module within DSSAT, which is well-suited for simulating the growth of field crops like sunflower, was used (Boote et al., 1998). The model requires detailed inputs, including daily weather data, soil characteristics, and crop management practices. DSSAT also includes advanced tools like the GLUE (Generalized Likelihood Uncertainty Estimation) module, which automatically calibrates genetic coefficients to optimize model performance (Jones et al., 2011). This makes DSSAT particularly useful for evaluating the effects of different irrigation schedules on sunflower yield.

WOFOST (World Food Studies) is a mechanistic model that simulates crop growth based on physiological processes (Van Diepen et al., 1989). It is used to analyze the potential yield of crops under varying environmental conditions. WOFOST requires inputs such as daily weather data, soil properties, and crop management practices. The model calculates the photosynthesis of crops as a function of temperature, solar radiation, and CO<sub>2</sub> concentration, while also considering the water and nitrogen balance within the soil (Van Ittersum et al., 2003). WOFOST is particularly effective for assessing the impact of water availability on crop growth and yield, making it an ideal tool for this study's focus on sunflower yield under different irrigation levels.

The RMSE, NRMSE, R<sup>2</sup> and EF values used to evaluate the performance of the simulation models were calculated using the formulas given below (Elsadek et al., 2023).

$$RMSE = \sqrt{\frac{\sum_{t=1}^n (u)^2}{n}} \quad (\text{Eq.3}).$$

$$NRMSE = \frac{1}{O^-} \sqrt{\sum_{i=1}^n \frac{(s_i - O_i)^2}{n}} \times 100 \quad (\text{Eq.4}).$$

$$R^2 = \left[ \frac{\sum_{i=1}^n (o_i - O^-) (s_i - s^-)}{\sqrt{\sum_{i=1}^n (o_i - O^-)^2} \sqrt{\sum_{i=1}^n (s_i - s^-)^2}} \right]^2 \quad (\text{Eq.5}).$$

$$EF = 1 - \frac{\sum_{i=1}^n (o_i - s_i)^2}{\sum_{i=1}^n (s_i - s^-)^2} \quad (\text{Eq.6}).$$

Where  $o_i$  represents the observed (measured) value,  $O^-$  stands for the mean observed value,  $s_i$  refers to the simulated value,  $s^-$  is the mean simulated value, and  $n$  denotes the total number of data points.  $R^2$  shows how effectively AquaCrop can explain the variance in measured data, with a value near 1 indicating a close match between the observed and simulated values. The results of RMSE, NRMSE, and EF were interpreted using the following criteria: an RMSE value of <10% indicates that the simulation is very good, RMSE= 10-20% is considered good, RMSE= 20-30% is medium, and RMSE= >30% is considered poor (Aydoğdu et al., 2023). NRMSE results were considered excellent when NRMSE < 10%, good/well at 10% NRMSE 20%, fair/acceptable at 20% NRMSE 30%, and poor when NRMSE > 30% (Elsadek, 2023). The EF value ranges from negative infinity to 1, where values between 0 and 1 typically indicate acceptable performance, while values < 0 suggest that the measured dataset is a better

predictor than the simulated dataset, reflecting unacceptable model performance (Moriassi et al., 2007).

These models collectively provided a robust framework for simulating sunflower growth under varying irrigation scenarios, allowing for the assessment of water use efficiency and yield optimization.

#### **2.4. Statistical analysis**

Statistical analysis of the obtained data was performed using SPSS software. A split-plot design with three replications was used for the experiment. Variance analysis (ANOVA) was conducted to assess the effects of the experimental treatments on the measured variables. Levene's test was applied to check the assumption of homogeneity of variances among the treatment groups. Upon confirming homogeneity, ANOVA was employed to examine differences in mean values. When significant differences were observed, Duncan's multiple-range test was used to compare the means between treatment groups (Gomez and Gomez, 1984).

### **3. Results**

#### **3.1. Vegetative growth and canopy analysis**

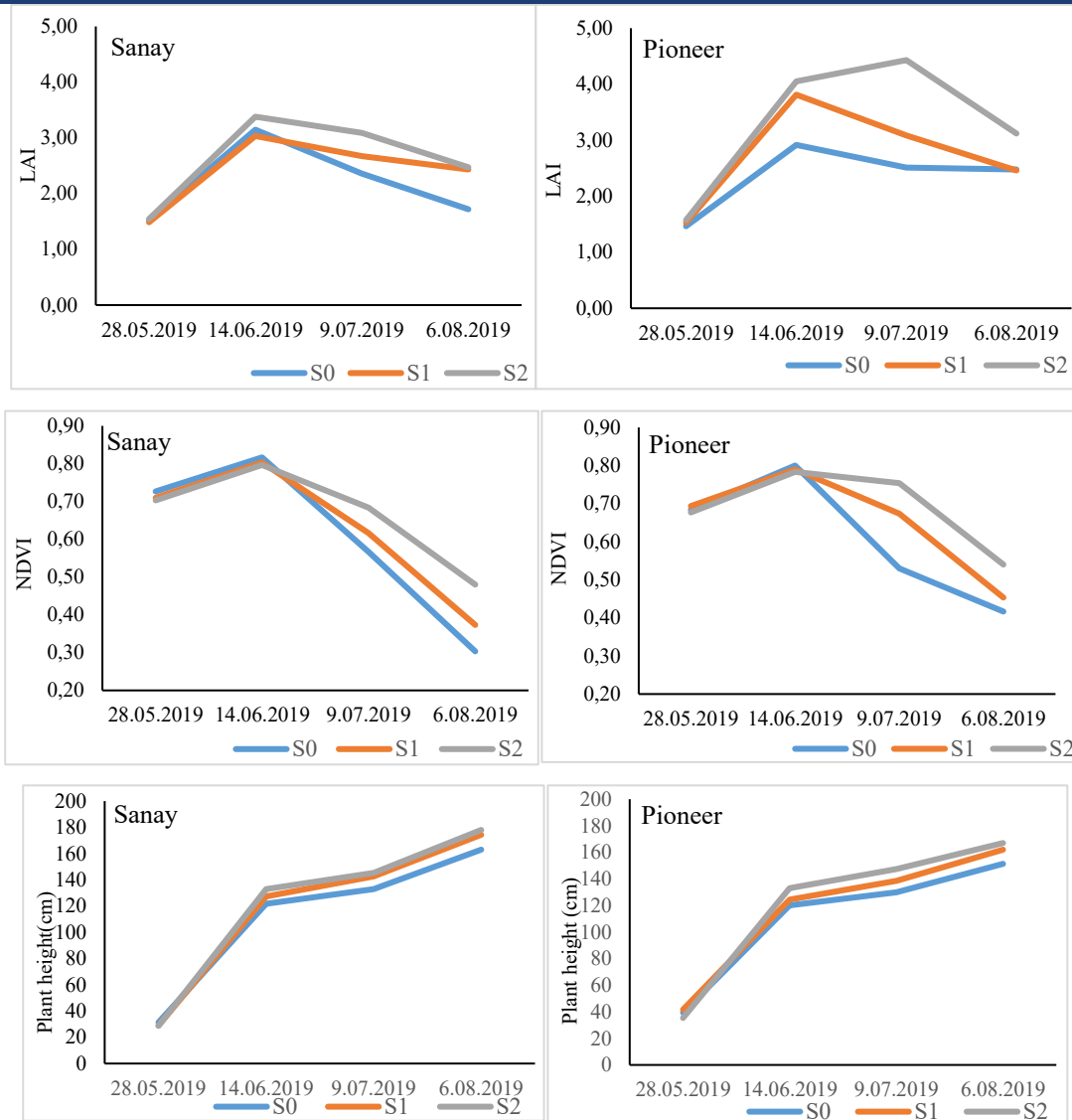
Leaf cover development of sunflower cultivars (Sanay and Pioneer) and different irrigation treatments (S0, S1, S2) were monitored by LAI and NDVI measurements taken at four different periods during the growing season. The results show that irrigation treatments had significant effects on leaf cover development and revealed significant differences between the two sunflower cultivars. These findings highlight the critical role of different irrigation strategies in enhancing vegetative growth, particularly in the case of the Pioneer cultivar.

In the early stages of growth, the LAI values for both Sanay and Pioneer were very close to each other, with the average LAI value for all subjects being approximately 1.50 at the end of the first developmental period. However, as the season progressed, marked differences emerged. On June 14, the LAI value for Sanay increased to 3.19 and for Pioneer to 3.59, indicating stronger vegetative growth and a better response to irrigation treatments for Pioneer. On July 9, a decrease in LAI values was observed for Sanay, which was 2.36, 2.67, and 3.09 for treatments S0, S1, and S2, respectively. In contrast, the Pioneer cultivar continued to grow, and the highest LAI value of 4.43 was recorded on this date, which was the highest LAI value obtained during the season in irrigation treatment S2. These results indicate that irrigation strategies, especially S2, play a critical role in increasing leaf area index. On the same date, S1 and S0 subjects recorded values of 3.08 and 2.51, respectively. These findings suggest that Pioneer responded better to irrigation, especially to irrigation subject S2, and higher LAI values were obtained throughout the irrigation season than Sanay (*Figure 2*).

NDVI measurements also showed that there were differences between sunflower varieties and irrigation treatments. In the early season (May 28 and June 14), no significant difference was observed between varieties and irrigation treatments. However, in the measurements made on July 9, it was observed that NDVI values varied between 0.57 and 0.68 in Sanay and between 0.53 and 0.75 in Pioneer. As the season progressed and the plants matured, NDVI values decreased. On August 6, NDVI values were 0.30, 0.37, and 0.48 for Sanay in S0, S1, and S2 treatments, respectively. On the same date, 0.41, 0.45, and 0.54 values were recorded for Pioneer cultivar in S0, S1, and S2 treatments, respectively. This trend indicates that Pioneer was able to maintain a viable leaf cover for a longer period with the S2 irrigation topic (*Figure 3*).

Plant height measurements showed that Sanay was taller than Pioneer. This difference was especially evident in the measurements made on August 6. Sanay reached the highest plant height values with S2 irrigation throughout the season. On August 6, the plant height values for Sanay were 163 cm, 174.33 cm, and 178 cm for S0, S1, and S2 irrigation subjects, respectively. On the same date, 151.33 cm, 162 cm, and 167 cm values were recorded for Pioneer in S0, S1, and S2 treatments, respectively.

In general, Pioneer showed superior leaf cover development with higher LAI and NDVI values, especially in S2 irrigation treatment. However, Sanay had higher plant height values compared to Pioneer. This indicates that Sanay may be advantageous in terms of physical growth, but Pioneer may be superior in potential yield by providing better vegetative development.



S0: No irrigation (control), S1: Half of the irrigation water amount applied in S2 S2: Full irrigation replenishing the soil moisture to field capacity every 15 days.

**Figure 2. Monthly temperature and rainfall averages for the years Leaf Area Index (LAI), Normalized Difference Vegetation Index (NDVI), and Plant Height measurements for sunflower varieties Sanay and Pioneer under different irrigation treatments.**

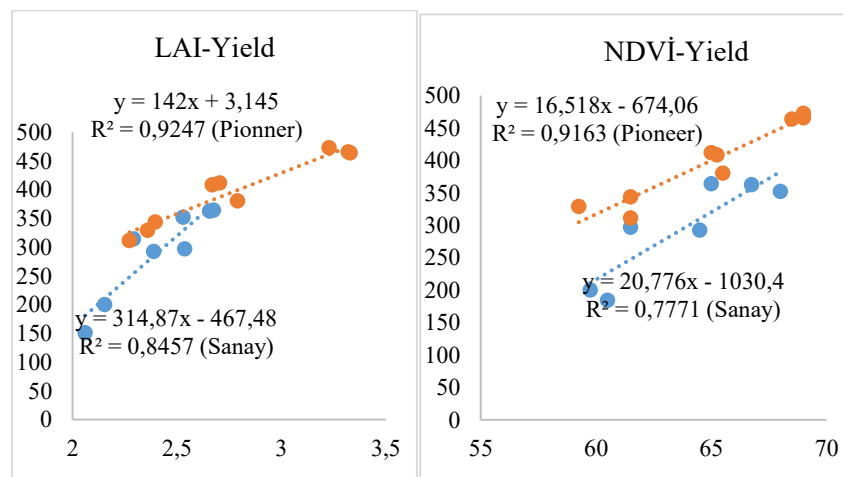


**Figure 3. Relationship between LAI and NDVI values and yield**

### 3.2. Biomass and yield

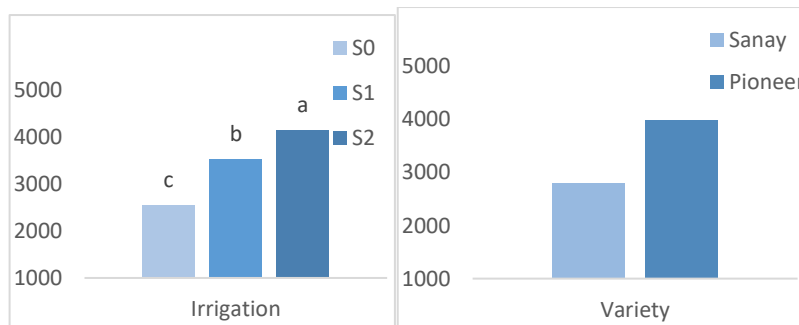
In this study, biomass and yield values of Sanay and Pioneer sunflower cultivars under different irrigation treatments (S0, S1, S2) were investigated. The effects of irrigation and seed varieties on these parameters were statistically analyzed. The results showed that both irrigation treatments and seed varieties had significant effects on biomass and yield (Table 4).

**Table 4. Yield and biomass results according to irrigation treatments and seed varieties**

|                                   | Treatment | Min   | Max   | Mean  | Variety | Irrigation | Variety*Irrigation |
|-----------------------------------|-----------|-------|-------|-------|---------|------------|--------------------|
| Yield<br>(kg ha <sup>-1</sup> )   | S0        | 1511  | 3438  | 2534  |         |            |                    |
|                                   | S1        | 2926  | 4119  | 3508  | 249**   | 153**      | 4.2*               |
|                                   | S2        | 3521  | 4729  | 4136  |         |            |                    |
| Biomass<br>(kg ha <sup>-1</sup> ) | S0        | 7469  | 13239 | 10887 |         |            |                    |
|                                   | S1        | 13844 | 17216 | 15349 | 49.9**  | 85.8**     | 1.4 <sup>ns</sup>  |
|                                   | S2        | 15669 | 21266 | 18389 |         |            |                    |

Variety: Sanay and Pioneer sunflower varieties; Irrigation: S0 (no irrigation), S1 (half irrigation), S2 (full irrigation); Variety\*Irrigation: Interaction between sunflower varieties and irrigation treatments. Levels of statistical significance are denoted as \* for  $p < 0.05$ , \*\* for  $p < 0.01$ , and ns for not significant.

The results show that irrigation treatments have a significant effect on yield. Significant increases in yield values were observed with increasing irrigation amounts. S2 irrigation treatment provided the highest yield for both Sanay and Pioneer varieties. While the average yield of Sanay was 3597 kg ha<sup>-1</sup> with S2 irrigation, this value was recorded as 4677 kg ha<sup>-1</sup> in Pioneer. These results indicate that increasing the amount of irrigation had a positive effect on yield and that the Pioneer responded better to irrigation treatments (Figure 4).



Group: Duncan's Multiple Range Test was used to indicate groups that show statistical differences.

**Figure 4. Yield according to irrigation subjects and seed varieties (kg ha<sup>-1</sup>)**

Biomass results showed that irrigation treatments had a significant effect on biomass production. However, the variety\*irrigation interaction was statistically significant in biomass results. This interaction reveals that Sanay and Pioneer varieties responded differently to irrigation treatments. While Sanay cultivar showed relatively high biomass production even in the non-irrigated S0 treatment, Pioneer cultivar reached the highest biomass values in the S2 irrigation treatment (Figure 5).

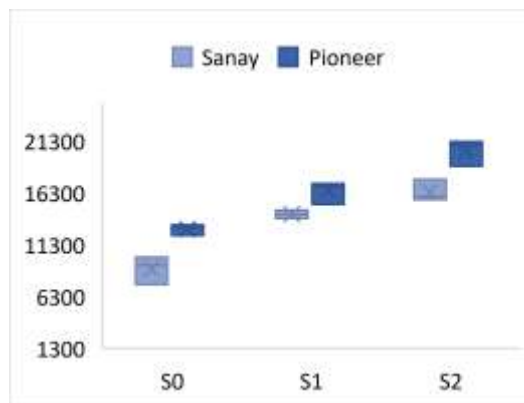


**Figure 5. Biomass (kg ha<sup>-1</sup>) by irrigation treatments and seed varieties**

In conclusion, irrigation treatments and seed varieties had significant effects on yield and biomass production in this study. Increasing the irrigation amount positively affected both parameters, but the cultivar\*irrigation interaction played an important role in biomass production.

### 3.3. Simulation-based yield predictions

In this study, sunflower yield was estimated using AquaCrop, DSSAT, and WOFOST simulation models. The yield predictions of the models were calculated for irrigation treatments (S0: no irrigation, S1: semi-irrigation, S2: full irrigation) and two sunflower cultivars (Sanay and Pioneer), and these predictions were compared with the actual yield values obtained. The AquaCrop model generally provided the closest predictions to the actual yield values for both varieties (Table 5). At irrigation treatment S2, the yield predicted by the AquaCrop model for the Pioneer was the closest to the actual yield.

**Table 5. Yield Prediction Results and Actual Yield Values of AquaCrop, DSSAT and WOFOST Simulation Models ( $\text{kg ha}^{-1}$ )**

| Variety | Treatment | Yield | AquaCrop | DSSAT | WOFOST |
|---------|-----------|-------|----------|-------|--------|
| Sanay   | S0        | 1780  | 1750     | 1840  | 2010   |
| Sanay   | S1        | 3010  | 3120     | 3310  | 3280   |
| Sanay   | S2        | 3590  | 3880     | 3950  | 3420   |
| Pioneer | S0        | 3280  | 3000     | 3180  | 3000   |
| Pioneer | S1        | 4000  | 3960     | 3900  | 3850   |
| Pioneer | S2        | 4670  | 4930     | 4420  | 4060   |

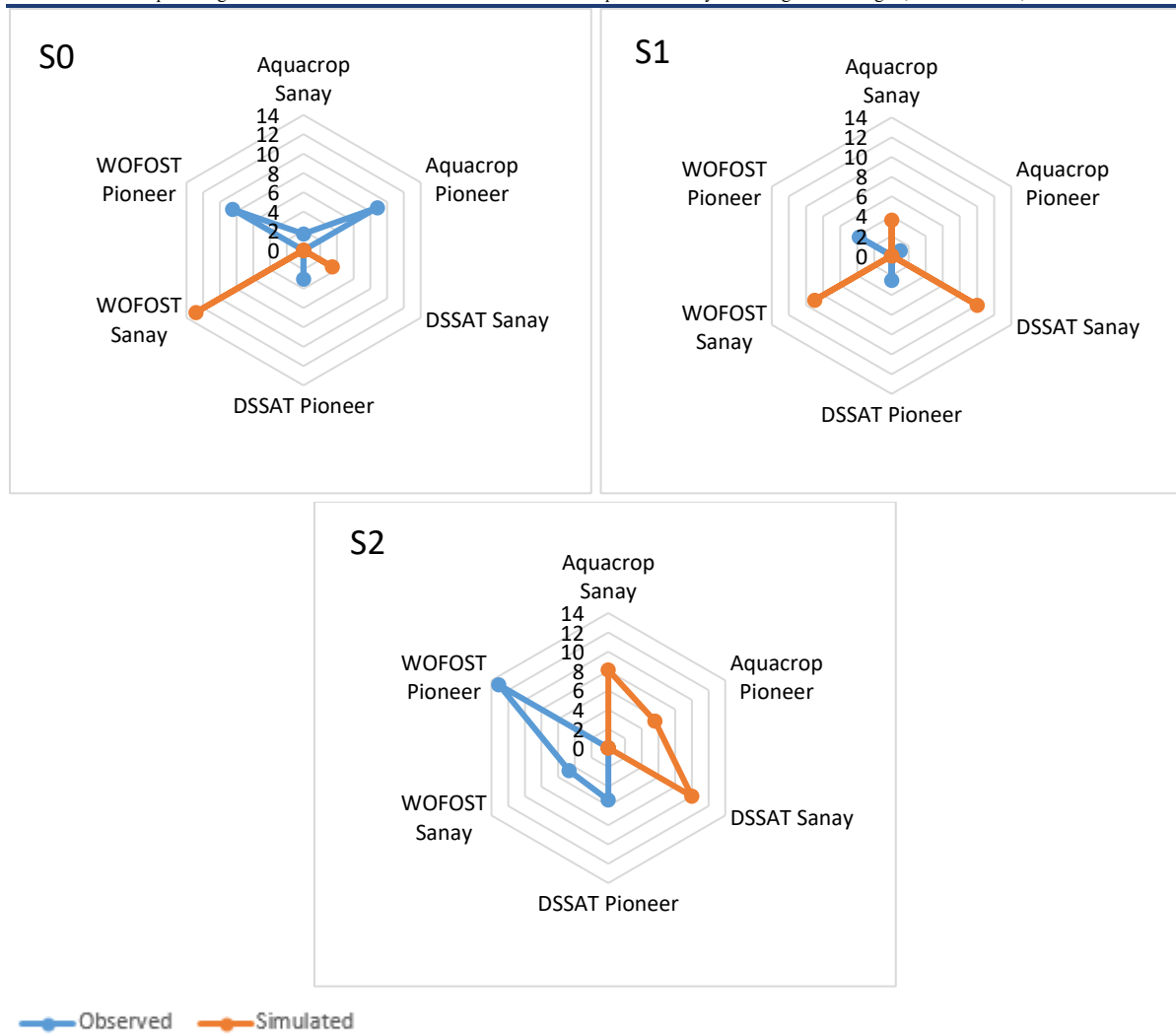
The DSSAT model showed higher deviations, especially for Sanay (Table 6). Although the predictions of this model were reasonably accurate for the Pioneer under irrigation treatments S0 and S1, the predictions were lower than the actual yield under irrigation treatment S2. The WOFOST model showed the largest deviations, especially for the Pioneer variety (Figure 6). This model provided a prediction 13.1% lower than the actual yield for the Pioneer under irrigation subject S2. This result indicates that the model is less reliable for this variety.

The differences between the estimated values and the actual yield values were determined by t test. According to the results of the statistical analysis, the difference between the yield values obtained in all three models and the actual yield values for both sunflower varieties was found statistically insignificant (Sanay-Aquacrop (p: 0.780), Pioneer-Aquacrop (p:0.946), Sanay-DSSAT (p:0.579), Pioneer-DSSAT (p: 0.581), Sanay-WOFOST (p: 0.771), Pioneer-WOFOST (p: 0.200).

Among the three models, AquaCrop consistently provided the most accurate predictions, particularly under full irrigation (S2), highlighting its effectiveness in water management scenarios. The DSSAT and WOFOST models presented less reliable results under different irrigation strategies, with larger deviations.

**Table 6. Deviations in Yield Prediction Results of AquaCrop, DSSAT and WOFOST Crop Simulation Models (% Deviation)**

| Treatments | Deviations in yield estimates (%) |         |       |         |        |         |
|------------|-----------------------------------|---------|-------|---------|--------|---------|
|            | AquaCrop                          |         | DSSAT |         | WOFOST |         |
|            | Sanay                             | Pioneer | Sanay | Pioneer | Sanay  | Pioneer |
| S0         | -1.7                              | -8.5    | +3.4  | -3.0    | +12.9  | -8.5    |
| S1         | +3.6                              | -1.0    | +10.0 | -2.5    | +9.0   | -3.8    |
| S2         | +8.1                              | +5.6    | +10.0 | -5.4    | -4.7   | -13.1   |



Each axis represents the percentage deviation in yield predictions of the simulation models across different irrigation treatments.

**Figure 6. Percentages of deviation in yield predictions of crop simulation models**

The performances of AquaCrop, DSSAT, and WOFOST simulation models were analyzed with RMSE, NRMSE, and EF values to evaluate the accuracy of yield predictions (Table 7). The calculated RMSE values of the AquaCrop model for Sanay and Pioneer varieties were 15.56 and 12.98, respectively. These results indicate that AquaCrop has a reliable simulation performance. The NRMSE values of the model were calculated as 7.30 and 10.82, which indicates that the simulation has a very high accuracy. Furthermore, the EF values of AquaCrop are 0.937 and 0.901, indicating that the model offers a strong performance in yield prediction.

The DSSAT model showed higher RMSE and NRMSE values (24.82 and 11.17), especially for Sanay, indicating some weaknesses in the prediction accuracy of the model. The RMSE and NRMSE values of the DSSAT model for the Pioneer were 23.81 and 8.49, respectively, indicating that the simulation results had relatively good accuracy. The EF values of the DSSAT model were 0.885 and 0.838 for Sanay and Pioneer varieties, respectively, indicating that there are certain limitations in the predictive capacity of the model, especially for Pioneer.

The WOFOST model provided the highest RMSE values (15.32 and 13.71) and the lowest EF values (0.829 and 0.828) for both sunflower cultivars, with a lower accuracy compared to the other models. The NRMSE values of the model were 11.64 and 14.75 for Sanay and Pioneer varieties, respectively, indicating that WOFOST has an acceptable accuracy.



**Table 7. RMSE, NRMSE and EF results of the crop simulation models**

| Parameter | AquaCrop |         | DSSAT |         | WOFOST |         |
|-----------|----------|---------|-------|---------|--------|---------|
|           | Sanay    | Pioneer | Sanay | Pioneer | Sanay  | Pioneer |
| RMSE      | 15.56    | 12.98   | 24.82 | 23.81   | 15.32  | 13.71   |
| NRMSE     | 7.30     | 10.82   | 11.17 | 8.49    | 11.64  | 14.75   |
| EF        | 0.937    | 0.901   | 0.885 | 0.838   | 0.829  | 0.828   |

The AquaCrop model performed particularly well under full irrigation (S2) (Figure 7). The DSSAT and WOFOST models presented less reliable results under different irrigation strategies, with larger deviations.

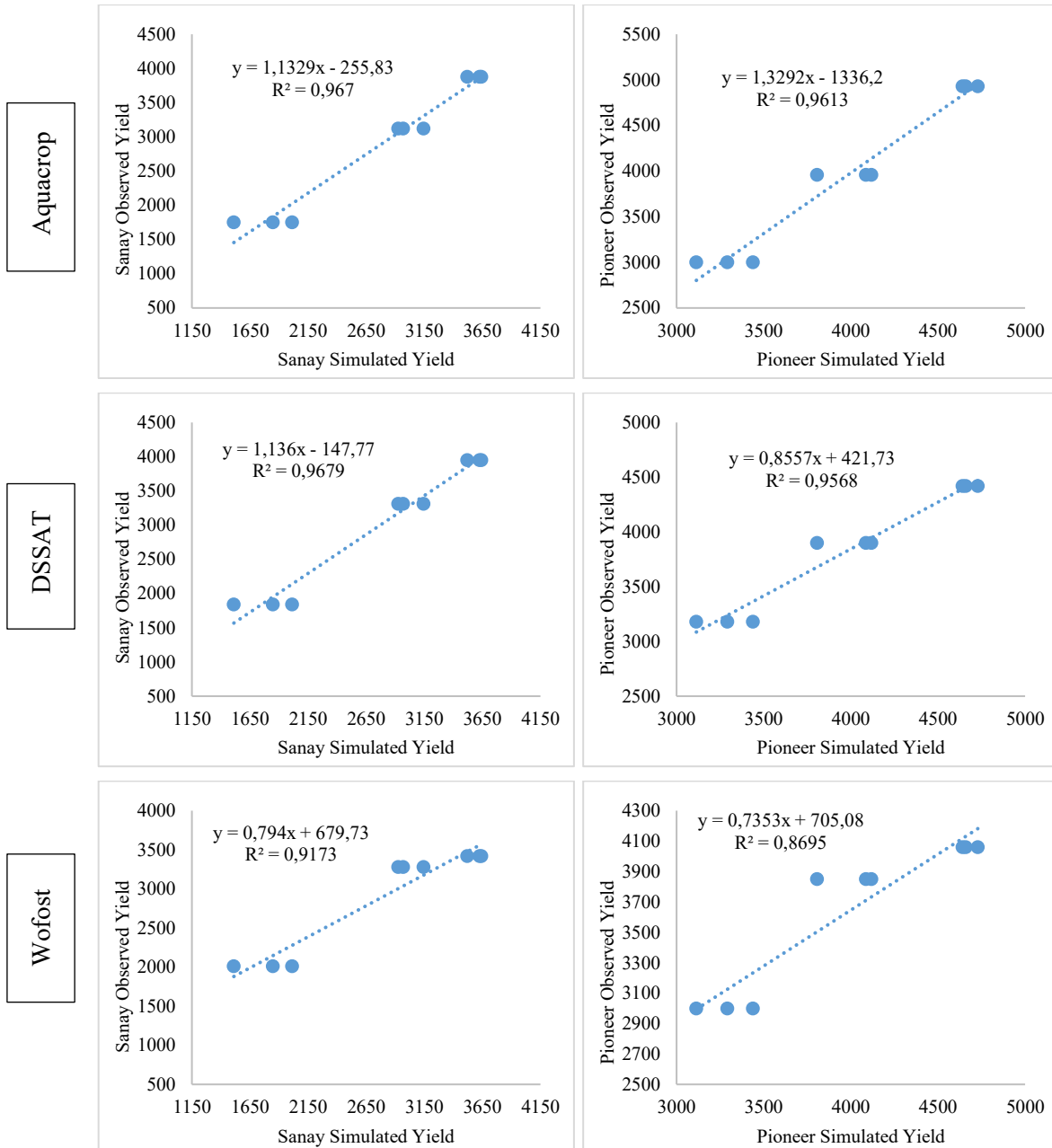


**Figure 7. Relationships between Yield Prediction Results of AquaCrop, DSSAT and WOFOST Simulation Models and Actual Yield Values.**

## 4. Discussion

### 4.1. Vegetative Growth and Biomass Yield Responses

The findings of this study reveal the effects of different irrigation strategies (S0, S1, S2) and sunflower cultivars (Sanay and Pioneer) on leaf cover development and biomass yield. The Pioneer variety exhibited higher LAI and NDVI values, especially under full irrigation (S2) conditions, indicating that this variety is better adapted to water stress and maintains its photosynthetic activity. These results align with previous studies, which show that efficient irrigation strategies can improve water use efficiency and plant growth under water-limited conditions (Todorovic et al., 2009; Garofalo and Rinaldi, 2015). This also highlights the role of proper irrigation management in maintaining photosynthetic efficiency and overall plant health, particularly for cultivars like Pioneer.

The Sanay variety was characterized by relatively high biomass production even under non-irrigated (S0) conditions. This suggests that Sanay may be advantageous in terms of physiological growth, but Pioneer may be superior in potential yield by providing a more efficient leaf cover. This is consistent with findings from other studies, where different irrigation strategies affected biomass and yield depending on the cultivar's response to water stress (Yiğit and Candoğan, 2019). Optimizing water management is crucial for ensuring high biomass production and improving water use efficiency (Wakeel, 2013).

In particular, full irrigation (S2) treatments resulted in the highest yield and biomass values for both varieties. These findings suggest that sunflower cultivars like Sanay can show high yield potential even under water constraints, which is critical for sustainable agricultural practices (Bingham and Martin, 1956). The variety and irrigation interaction observed in this study highlights the importance of cultivar selection in relation to specific irrigation strategies, especially under varying water conditions. Proper irrigation management and variety selection are therefore key strategies for enhancing sunflower production under water scarcity conditions (Zhang et al., 2021).

In the context of climate change, understanding the impacts of irrigation strategies on sunflower yields and optimizing these strategies is vital for future food security. Sustainable water management strategies will play a crucial role in agricultural productivity, especially under increasing water stress due to climate change (Eltarabily et al., 2020).

### 4.2. Simulation Models for Yield Prediction

The simulation models used in this study (AquaCrop, DSSAT, and WOFOST) were evaluated to predict sunflower yield. The performance of the models was compared for different irrigation strategies (S0: no irrigation, S1: semi-irrigation, S2: full irrigation) and two sunflower varieties (Sanay and Pioneer). Among these models, AquaCrop consistently provided the most accurate predictions, especially under full irrigation (S2) conditions, indicating that its water-based growth engine functions effectively in predicting plant responses to water availability (Steduto et al., 2009; Razzaghi et al., 2017).

AquaCrop demonstrated a reliable performance, particularly when RMSE and EF parameters were considered. These results confirm that AquaCrop is a powerful tool for water management strategies, offering accurate yield predictions under both water-limited and fully irrigated conditions (Mokhtar and Kasem, 2021). In contrast, the DSSAT model showed lower EF and higher RMSE values, particularly for certain irrigation strategies and sunflower varieties. This suggests that the DSSAT model requires careful calibration and adaptation to environmental conditions to improve its predictive accuracy (Abedinpour, 2021).

When evaluated in terms of NRMSE and EF values, the WOFOST model demonstrated lower accuracy compared to AquaCrop and DSSAT. The model's performance was particularly weak under water-stressed conditions, as seen with the Pioneer variety, where WOFOST provided predictions 13.1% lower than the actual yield under full irrigation (S2). These results indicate that WOFOST may be more sensitive to water stress and less reliable for predicting yields in such conditions (Zhu et al., 2018).

This study reveals that the differences in yield predictions between simulation models should be carefully considered when implementing water management strategies. AquaCrop, once again, has proven its usefulness in agricultural water management, providing the most accurate predictions under full irrigation conditions (Raes et al., 2009; Steduto et al., 2009). These findings align with other literature that highlights AquaCrop's role as a reliable tool for predicting water use efficiency (WUE) and yield under water-stressed conditions (Soothar et al., 2021). Accurate calibration and the appropriate selection of simulation models for specific environmental conditions are critical for optimizing agricultural yield predictions and ensuring sustainability (Abedinpour, 2021).

Many studies have examined the performance of different simulation models in yield prediction, considering environmental conditions. These studies emphasize that while AquaCrop is a powerful tool, especially under water-scarcity conditions, models like DSSAT and WOFOST also offer advantages under specific circumstances (Ran et al., 2020).

Accurate calibration and the selection of appropriate simulation models play a major role in enhancing yield predictions and optimizing agricultural production strategies, especially in the context of climate change and water scarcity.

## **5. Conclusions**

In this study, the use of yield prediction models (Aquacrop, WOFOST, DSSAT) in sunflower varieties grown under different water constraints and their adaptation to the region were tested. The results demonstrated that the full irrigation strategy (S2) produced the highest yield and biomass values in both Sanay and Pioneer varieties. Pioneer exhibited higher LAI and NDVI values, particularly under full irrigation conditions, suggesting that it is more resilient to water stress. On the other hand, Sanay showed relatively high biomass production even under non-irrigated conditions, highlighting that different seed varieties can maintain high yield potential under varying water constraints.

The use of simulation models, particularly AquaCrop, was shown to be a valuable tool for water management and yield prediction. AquaCrop provided the most accurate predictions, especially under full irrigation, reinforcing its effectiveness for simulating crop responses to water availability. In contrast, the DSSAT and WOFOST models displayed variable performances under different environmental conditions, emphasizing the need for precise model calibration.

These findings suggest that sunflower yield can be sustainably increased by optimizing water management strategies and selecting the right seed variety for specific water conditions. This is especially critical in the context of climate change, where water scarcity is expected to become more prevalent. The study's results provide valuable insights for improving agricultural sustainability and enhancing food security under water-limited conditions.

Future research should focus on assessing the long-term effectiveness of these strategies and validating these findings across different environmental conditions. Additionally, detailed calibration studies are needed to further improve the accuracy of simulation models across various agricultural systems. These efforts will contribute to the global goal of optimizing agricultural production strategies, ultimately supporting global food security.

## **Acknowledgment**

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## **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

## **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

## **Authorship Contribution Statement**

Concept: Öztürk, O., Bahar, E.; Design: Özer, S., Kıvrak, C.; Data Collection or Processing: Gür, M., Bakanoğulları, F.; Statistical Analyses: Atav, V., Öztürk, O.; Literature Search: Bahar, E., Özer, S.; Writing, Review and Editing: Kıvrak, C., Öztürk, O.

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**Valorization of Livestock Manure and Agricultural Residue for Biogas-Based Circular Economy in Kırklareli Province, Türkiye**

Türkiye, Kırklareli İlinde Biyogaz Bazlı Döngüsel Ekonomi İçin Hayvan Gübresi ve Tarımsal Artıkların Değerlendirilmesi

Betül ÖZER<sup>1\*</sup>

**Abstract**

Energy consumption is increasing due to population growth, rising prosperity, and the rapid advancement of technology. The predominant use of fossil fuels, which account for 81% of global energy consumption, has led to significant environmental problems, particularly climate change. Climate change has been a key global issue for the past two decades. The Paris Agreement, adopted at COP21 in 2015, marked the first global commitment to reducing greenhouse gas emissions post-2020. In 2019, the European Union (EU) launched the European Green Deal (EGD), aiming to limit global temperature rise to below 2°C and adapt to climate change. The EU's goal is to become the first climate-neutral continent by 2050, reshaping its policies across sectors like industry, energy, transportation, and agriculture. This study emphasizes the benefits of greenhouse gas (GHG) mitigation, particularly focusing on the generation of bio-methane derived from livestock manure and agricultural residue in the Kırklareli province of Türkiye. This study also examines CH<sub>4</sub> emissions released by the livestock sector due to processes of enteric fermentation and manure management. According to the results obtained, bio-methane has a potential electricity generation capacity of 566 GWh year<sup>-1</sup>. CO<sub>2</sub> emissions from biogas energy production are calculated as 261492 tons CO<sub>2</sub>eq year<sup>-1</sup>. Accordingly, the CO<sub>2</sub> emission mitigation capacity is determined to be between 310969 and 443799 tons CO<sub>2</sub>eq year<sup>-1</sup> based on the IPCC Guidelines' Middle East, Eastern Europe, and Asia values. This study also examines CH<sub>4</sub> emissions released by the livestock sector due to processes of enteric fermentation and manure management. Enteric fermentation and manure management -based CO<sub>2</sub>eq emissions were calculated according to Tier 1 and Tier 2 approaches given in the IPCC Guidelines. This study aims to provide policymakers and relevant stakeholders with comprehensive information regarding the diversification of the energy mix. It emphasizes the benefits of GHG mitigation, particularly focusing on the generation of bio-methane derived from livestock manure and agricultural residues in the Kırklareli province of Türkiye.

**Keywords:** Waste to energy, Manure management, GHG, CO<sub>2</sub> mitigation, Bio-methane, Circular economy, Energy potential

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## Öz

Nüfus artışı, artan refah ve teknolojinin hızla ilerlemesi nedeniyle enerji tüketimi artmaktadır. Küresel enerji tüketiminin %81'ini oluşturan fosil yakıtların baskın kullanımı, özellikle iklim değişikliği olmak üzere önemli çevre sorunlarına yol açmaktadır. İklim değişikliği, son yirmi yıldır önemli bir küresel sorun olmuştur. 2015 yılında COP21'de kabul edilen Paris Anlaşması, 2020 sonrası sera gazı emisyonlarını azaltmaya yönelik ilk küresel taahhüdü temsil etmektedir. Avrupa Birliği (AB), 2019 yılında küresel sıcaklık artışını 2°C'nin altında sınırlamayı ve iklim değişikliğine uyum sağlamayı amaçlayan Avrupa Yeşil Mutabakatı'nı (AYM) başlattı. AB'nin hedefi, sanayi, enerji, ulaştırma ve tarım gibi sektörlerdeki politikalarını yeniden şekillendirerek 2050 yılına kadar ilk iklim nötr kıta olmaktır. Bu çalışma, özellikle Türkiye'nin Kırklareli ilinde hayvan gübresi ve tarımsal artıklardan elde edilen biyometan üretimine odaklanarak sera gazı azaltımının faydalarını vurgulamaktadır. Bu çalışmada ayrıca, hayvancılık sektörü tarafından enterik fermentasyon ve gübre yönetimi süreçleri nedeniyle salınan CH<sub>4</sub> emisyonları da incelenmiştir. Elde edilen sonuçlara göre biyometan, 566 GWh yıl<sup>-1</sup> potansiyel elektrik üretim kapasitesine sahiptir. Biyogaz enerji üretiminden kaynaklanan CO<sub>2</sub> emisyonları 261492 ton CO<sub>2</sub>eq yıl<sup>-1</sup> olarak hesaplanmıştır. Buna göre, IPCC Kılavuzu'nun Orta Doğu, Doğu Avrupa ve Asya değerleri baz alınarak CO<sub>2</sub> emisyonu azaltma kapasitesi 310969 ile 443799 ton CO<sub>2</sub>eq yıl<sup>-1</sup> arasında olduğu belirlenmiştir. Bu çalışmada ayrıca, hayvancılık sektörü tarafından enterik fermentasyon ve gübre yönetimi süreçleri nedeniyle salınan CH<sub>4</sub> emisyonları da incelenmiştir. Enterik fermentasyon ve gübre yönetimi bazlı CO<sub>2</sub>eq emisyonları IPCC Kılavuzunda verilen Tier 1 ve Tier 2 yaklaşımlarına göre hesaplanmıştır. Bu çalışma, politika yapıcılara ve ilgili paydaşlara enerji karışımının çeşitlendirilmesi konusunda kapsamlı bilgi sağlamayı amaçlamaktadır. Özellikle Türkiye'nin Kırklareli ilinde hayvan gübresi ve tarımsal artıklarından elde edilen biyometan üretimine odaklanarak sera gazı azaltımının faydalarına vurgu yapmaktadır.

**Anahtar Kelimeler:** Atıktan enerji, Gübre yönetimi, SGE, CO<sub>2</sub> azaltımı, Biyo-metan, Döngüsel ekonomi, Enerji potansiyeli

## 1. Introduction

Energy has become an important indicator that determines the development level of countries around the world. Population growth, rising levels of prosperity and rapid technological development can be determined as the main factors of increasing energy consumption. Accordingly, a significant portion, approximately 81%, of the world's energy supply comes from fossil fuels. (Anonymous, 2024a). This excessive use of fossil fuels leads to a rapid depletion of resources, and environmental problems, particularly climate change pose a threat to the world. On the other hand, one of the important factors that enable countries to progress economically is sustainability in energy. Accordingly, the structure of economies, energy consumption patterns and even lifestyles are changing around the world. Fossil fuels, mentioned as the most responsible for climate change, are being replaced by renewable, sustainable and clean energy sources. Extracting energy from biomass and utilizing its energy potential can be used to generate fossil fuel-free energy while reducing the amount of waste that needs to be disposed of. Climate change has been the most important global issue on the world's agenda, mostly for the past two decades. The Paris Agreement, which forms the framework for the post-2020 climate change regime, was adopted at the Conference of the Parties (COP) 21 in 2015. At COP21, all countries committed for the first time at a global level to reduce greenhouse gas (GHG) emissions after 2020. Accordingly, within the scope of combating global climate change, the EU published the European Green Deal (EGD) declaration in 2019. This initiative launched the transition to a green economy in line with the Paris Climate Agreement, aiming to keep the global temperature increase below 2°C and adapt to the effects of climate change. Consequently, the EU has set the goal of becoming the first climate-neutral continent in 2050 and announced that it will adopt a new growth strategy to achieve this goal and reshape all its policies around climate change. The EGD, envisages comprehensive changes in EU policies in many areas ranging from industry to finance, from energy to transportation and from buildings to agriculture. The green economy refers to the circular economy model with new policies covering all sectors as a solution to the climate crisis with resource efficiency and low carbon emissions (Küçük and Dural, 2022, Arslanhan, 2023). In addition, the transition to a low-carbon economy with the Circular Economy Action Plan envisages radical changes in countries' lifestyles as the basis for growth strategies and sustainable development goals in all sectors, especially in energy, agriculture and food security policies. At the beginning of this radical change is the reduction of CO<sub>2</sub> emission factors (EFs) in the energy sector, especially in electricity generation, which can be achieved through the increased use of renewable energy resources. Biomass energy is one of the most important renewable energy resources to achieve this increase, as it is constantly available and contributes to waste management. The utilization of biomass for energy production plays a significant role in diminishing dependence on fossil fuels and reducing GHG emissions. It facilitates the reintegration of waste into the economy, mitigates global warming and environmental pollution, assists in waste management, and fosters employment opportunities for local communities. Consequently, it contributes significantly to regional development. In recent years, waste from the agriculture and livestock sector has been extensively investigated, especially for its potential to mitigate methane (CH<sub>4</sub>) emissions, which is one of the significant GHGs causing climate change (Arslanhan, 2023; Ersoy and Uğurlu, 2020; Kaykioğlu and Cantekin, 2023; Görmüş, 2018; Köse and Görmüş, 2018; Köse 2017; Özer and Bayar, 2018; Aktaş et. al, 2015). Türkiye possesses substantial potential in terms of biomass resources depending on agriculture and livestock that can be harnessed and utilized as a significant energy source. Biomass energy needs to be utilized near its point of origin, resulting in reduced environmental impacts and costs associated with transportation. Therefore, regional utilization is crucial.

In this study, electricity production based on the bio-methane derived from livestock manure and agricultural residues through anaerobic digestion (AD) technology, along with the corresponding CO<sub>2e</sub> emission reduction for Kırklareli province, located in the Marmara Region of Türkiye, has been calculated. The aim of this study is to furnish policymakers and relevant stakeholders with comprehensive information regarding the diversification of the energy mix. It emphasizes the benefits of GHG mitigation, particularly focusing on the generation of renewable energy derived from livestock and agricultural wastes in Kırklareli. This study examines also CH<sub>4</sub> emissions released by its livestock sector due to processes of enteric fermentation and manure management (MM). The novelty of this study lies in demonstrating the GHG emissions that will be avoided by obtaining energy from livestock manure and agricultural residues to prevent climate change and in highlighting the contribution of waste to energy production within the circular economy. Previous studies did not reveal the contribution to preventing climate change by calculating the GHG avoided due to supplying energy from bio-methane. This is important

because it is the initial study on the mitigation of GHG emissions by using livestock manure and agricultural residues as a renewable energy source instead of fossil fuels, particularly lignite and hard coal, for Kırklareli encompassing all its districts. Additionally, specific CH<sub>4</sub> conversion rates for animal manure, derived from laboratory results, were employed.

Several studies have been conducted on bio-methane production from organic wastes as a renewable energy source both regionally and globally, aiming to reduce dependence on fossil fuels and mitigate GHG emissions. Karaca (2023) investigated the biogas potential of animal manure for Konya Province in Türkiye, resulting in a potential of 266.53 GWh for electricity generation. Altan et al. (2022) mentioned that the AD of livestock wastes could provide approximately 10% of the total electricity consumption for Türkiye in 2018. Şenol et al., (2021) presented Türkiye's bovine manure-based bio-methane potential with a valuation of the spatial distribution by year and province with forecasts extending to 2030. Melikoğlu and Menekşe (2020) forecasted Türkiye's cattle and sheep manure bio-methane potential (BMP) will be 2.14 billion m<sup>3</sup>, with 57.9 million animal population and nearly 6600 GWh electricity generation by 2026. Ersoy and Uğurlu (2020) examined GHG emissions from Türkiye's livestock sector due to enteric fermentation and MM by province. Two scenarios were developed for total and realistic manure recovery rates varying by livestock category, with results indicating 8.41 billion m<sup>3</sup> and 4.18 billion m<sup>3</sup> biogas potential for Scenario 1 and Scenario 2 in 2015, respectively. Avcıoğlu et. al., (2019), determined the available annual energy potential of agricultural biomass residues in Türkiye as ranging from 159050 to 482864 TJ, with an average of 298955 TJ for arable agricultural field crops. Hossain et al., (2023) investigated the potential energy resources from livestock manure to evaluate the energy potential of Bangladesh from domestic animals including cows, chickens, sheep, and goats. A comparative analysis of four scenarios including AD, gasification, combustion and direct combustion to heat energy generation is exclusively examined with cogeneration. The gasification process with heat recovery options has the greatest energy estimation with 26564.64 TJ. The CO<sub>2</sub> reduction potentials of the scenarios were evaluated. Liu et al., (2023) evaluated the biogas potential of agricultural waste in Hubei Province, China. The biogas potential was estimated to be  $4.67 \times 10^9$  m<sup>3</sup>, which could result in a carbon emission reduction of  $2.33 \times 10^6$  tCO<sub>2</sub>. A substantial difference was observed between the estimated potential and actual biogas production, with an average discrepancy rate of 96.83%. Additionally, there was regional variation within Hubei, where only 0.5% of the areas with the lowest densities accounted for those with the highest densities. Kapoor et al., (2020) explored the valorization of agricultural waste for a biogas-based circular economy in India. The study evaluated the potential, utilization, and policy frameworks related to biogas production from agricultural waste. Products derived from AD, including high-value outputs like bio-methane, digestate, and by-products such as bio-CO<sub>2</sub>, were identified as key contributors to supporting the transition towards a bio-circular economy. Khalil et. al., (2019) investigated the potential of biogas production from animal waste in Indonesia as a waste-to-energy technology through AD. Animal waste, including manure, blood, and rumen contents, was found to have a biogas potential of 9597.4 Mm<sup>3</sup> year<sup>-1</sup>, which could generate over  $1.7 \times 10^{10}$  kWh of electricity annually. Aktaş et al., (2017) investigated the energy potential of rice straw as 100% straw pellet and pellet mixture with 15% coal powder with a laboratory scale gasifier. Çoban (2023) determined the payback period of a 3 MW electricity production capacity of a biogas plant as 4.24 years by the fertilizer sales obtained from the plant.

Some of the studies in the literature regarding GHG emissions from enteric fermentation and MM in Türkiye are also evaluated in this section. Karaca (2023) studied the energy potential of animal manure (dairy cattle, broilers, and laying hens) in the Konya province, Türkiye. Methane EFs were calculated using the Tier 2 methodology as 67.65 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup> for dairy cattle, 0.013 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup> for broilers, and 0.0286 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup> for laying hens. The CH<sub>4</sub> EF for MM from dairy cattle was found to be 67.65 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>, which is very high compared to enteric fermentation EFs. For broilers and laying hens, the results were within the range of values given by IPCC (2006) for developing countries. Kumaş and Akyüz (2023) calculated CH<sub>4</sub> emissions for the period 2016-2020 in the Lake District of Türkiye from enteric fermentation and MM using the IPCC Tier 1 approach. For enteric fermentation, they employed Eastern European methane EFs for cattle (99 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup> for dairy cattle and 58 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup> for other cattle) and developed country values for sheep (8 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>) and goats (5 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>). For MM, they used temperature-based Middle Eastern values for cattle and buffalo, while developing country values were applied for sheep, goats, horses, donkeys, mules, and poultry. The CH<sub>4</sub> emissions from MM were found to be 1.43% of those from enteric

fermentation, with 1567000 tons of CH<sub>4</sub> emitted from enteric fermentation and 22450 tons from MM. Yaylı and Kılıç (2021) calculated CH<sub>4</sub> EFs for the enteric fermentation of cattle in Türkiye using the IPCC Tier 2 methodology, finding 47 kg CH<sub>4</sub>/head-year for lactating cows and 52.5 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup> for bulls. The average EF in the cattle/buffalo category was calculated as 34.3 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>. Compared to the IPCC (2006) Tier 1 values, which range from 68-47 kg CH<sub>4</sub>/head-year for dairy and other cattle in Asia and 46-31 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup> for dairy cattle and other cattle in the Middle East, the values in the study were similar to those in Asian and the Middle East countries and lower than those in European countries. Kara et al., (2019) estimated GHG emissions from the enteric fermentation of animal manure in Konya Province, Türkiye, using IPCC Tier 1 EFs. They applied Asian values for cattle and developed country values for sheep and goats. The total CH<sub>4</sub> emissions from enteric fermentation in 2017 were determined to be 1110.14 Gg, which included emissions from cattle, buffalo, sheep, goats, camels, horses, mules, and donkeys. Öztürk and Ünal (2011) calculated the CH<sub>4</sub> EF from MM for the Tire-İzmir Region of Türkiye using the IPCC Tier 2 methodology. They identified solid and pit storage, daily spread, and paddock as the main manure storage systems in the region. They assumed an Asian Tier 1 EF for CH<sub>4</sub> from MM as 16 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>, whereas their study obtained a value of 2.05 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>.

## 2. Materials and Methods

In this study, the electrical energy that can be produced based on the bio-methane potential in Kırklareli has been calculated, using up-to-date data from the Turkish Statistical Institute (TurkStat) for the year 2023, considering livestock manure and agricultural residue. The bio-methane generation capacity through AD of manure and agricultural residue at the district level is examined. AD is one of the most effective GHG mitigation options for MM. The direct CH<sub>4</sub> emissions from livestock via enteric fermentation and MM are also examined. Kırklareli is located in the Marmara Region of Türkiye on the European Continent, between 41°44'–42°00' Northern Latitudes and 26°53'–41°44' Eastern Longitudes, with a land area of 6555 km<sup>2</sup>. It shares a border with Bulgaria to the north, and is bordered by the Black Sea along its eastern coastline, Edirne to the west, and Tekirdağ to the south (*Figure 1*). In Kırklareli, the share of the agricultural sector in the city's 2023 Gross Domestic Product (GDP) was 11%, amounting to approximately 536 million USD (Anonymous, 2025).



**Figure 1. Kırklareli Province map**

### 2.1 Animal production in Kırklareli

In this study, manure from cattle, small ruminants, and poultry were considered for bio-methane production. The data for the cattle category includes dairy cattle (purebred, crossbred, and domestic) and buffalo. For the small ruminant category, merino sheep, domestic sheep, and Angora goats were included. The poultry category consists of turkey, goose, duck, egg-laying chicken, and broiler (meat) chicken. Since manure generation varies with the age of the animals, age groups for cattle and small ruminants were also taken into account. *Table 1* presents the distribution of the total number of animals in Kırklareli by district (Anonymous, 2024b).

The districts of Central, Lüleburgaz, and Pınarhisar represent the top three in terms of animal population, collectively accounting for approximately 80% of the total animal population in Kırklareli. Conversely, the Pehlivan köy district exhibits the lowest level of animal population. Among all categories, poultry represents the highest population.

**Table 1. Animal population for Kırklareli by the district in 2023**

| District     | Cattle |        | Small Ruminant |        | Poultry | Total   |
|--------------|--------|--------|----------------|--------|---------|---------|
|              | Young  | Adult  | Young          | Adult  |         |         |
| Central      | 13006  | 32304  | 477            | 137521 | 327805  | 511113  |
| Lüleburgaz   | 17383  | 34986  | 841            | 50112  | 201919  | 305241  |
| Pınarhisar   | 2050   | 5229   | 881            | 55114  | 64821   | 128095  |
| Babaeski     | 6245   | 18957  | 695            | 38068  | 54244   | 118209  |
| Koçaz        | 1082   | 3131   | 631            | 32763  | 15043   | 52650   |
| Vize         | 2139   | 8780   | 790            | 30452  | 9323    | 51484   |
| Demirköy     | 1108   | 3105   | 1425           | 11490  | 3943    | 21071   |
| Pehlivan köy | 687    | 1832   | 0              | 6518   | 6915    | 15952   |
| Total        | 43700  | 108324 | 5740           | 362038 | 684013  | 1203815 |

## 2.2 Agricultural production in Kırklareli

Agricultural crop statistics were the main data source for calculating the agricultural residue biomass potential of Kırklareli. The annual production by cereal type per district is presented in Table 2 (Anonymous, 2024c). The districts of Lüleburgaz, Central, and Babaeski stand out for their significant agricultural production, collectively constituting 78% of the total production in Kırklareli. Conversely, the Demirköy district has the smallest area dedicated to plant production. Wheat and sunflower cultivation comprise the majority of crops in the city.

**Table 2. Agricultural production by cereal types per district, ton year<sup>-1</sup>**

| Crops        | Wheat  | Barley | Rye | Oat  | Maize | Rice  | Sunflower | Total  |
|--------------|--------|--------|-----|------|-------|-------|-----------|--------|
| Lüleburgaz   | 144494 | 8733   | 12  | 152  | 878   | 1219  | 61282     | 216770 |
| Central      | 70571  | 5608   | 608 | 1906 | 29157 | 0     | 57087     | 164937 |
| Babaeski     | 113356 | 5076   | 138 | 131  | 4365  | 7455  | 33854     | 164375 |
| Vize         | 44359  | 1736   | 0   | 251  | 126   | 0     | 15478     | 61950  |
| Pınarhisar   | 32037  | 1656   | 140 | 286  | 266   | 0     | 13754     | 48139  |
| Pehlivan köy | 15844  | 392    | 0   | 133  | 192   | 5873  | 4991      | 27425  |
| Koçaz        | 10713  | 902    | 21  | 2556 | 0     | 0     | 3862      | 18054  |
| Demirköy     | 156    | 88     | 0   | 89   | 0     | 0     | 0         | 333    |
| Total        | 431530 | 24191  | 919 | 5504 | 34984 | 14547 | 190308    | 701983 |

## 2.3 Direct CH<sub>4</sub> emissions from livestock

### 2.3.1. Enteric fermentation

CH<sub>4</sub> emissions from livestock refer to those produced through enteric fermentation and manure excretion. Methane is emitted directly by livestock as a by-product of digestion via enteric fermentation. According to Türkiye's total CH<sub>4</sub> emissions for 2021, agriculture accounts for the largest share at 61.43%, with 54.6% resulting from enteric fermentation and 6.23% from MM. Enteric fermentation constitutes approximately 89% of the emissions within the agriculture sector, while MM accounts for 10% (Anonymous, 2024d). Based on the IPCC methodology (IPCC, 2006), CH<sub>4</sub> emissions from enteric fermentation can be estimated using the EFs depending on the animal type and region, as outlined in the Tier 1 approach. Considering the values used in similar studies for Türkiye and the country's geographical location, the EFs for three regions, Eastern Europe, Asia, and the Middle East are applied (Table 3). The EFs are given separately for dairy and cattle for the Tier 1 approach. Since cattle population data is available only disaggregated by age, the average values of the separately calculated emissions were utilized.



**Table 3. Tier 1 approach enteric fermentation EF, kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup> (IPCC, 2006)**

|                                             | Eastern Europe | Asia | Middle East |
|---------------------------------------------|----------------|------|-------------|
| Dairy Cattle                                | 99             | 68   | 46          |
| Other Cattle                                | 58             | 47   | 31          |
| Small ruminants young and adult (45-65 kg)* | 5              | 5    | 5           |

\*: developing countries

**2.3.2. Manure management (MM)**

CH<sub>4</sub> emissions are released into the atmosphere under the anaerobic decomposition of manure during handling, storage, and treatment processes. These emissions are generally much less than those resulting from enteric fermentation. When manure is stored openly or deposited onto pastures, it decomposes under aerobic conditions, resulting in reduced CH<sub>4</sub> production. Consequently, their energy content cannot be evaluated. This leads to both the loss of energy sources and improper waste disposal, which have detrimental effects on the environment. Furthermore, there is a lack of utilization of manure as fertilizer. In Türkiye, animal manure is stored and disposed of using varying methods in different regions and at different rates. These methods include open storage, liquid or solid management systems including lagoons, ponds, pits, pastures, and daily spread. Manure is typically stored in a solid bulk form outside of the barn, in paddocks, and the in pits of dairy farms (Süslü and Seyfi, 2016; Öztürk, 2009; Kayar, 2011; Erkan, 2005).

**Tier 1 Approach**

CH<sub>4</sub> EFs are classified according to the animal type, the region, and the annual average temperature of the region in the Tier 1 methodology outlined by the IPCC (2006). EFs for cattle are determined by geographical regions, whereas those for small ruminants and poultry are categorized by the classification of developed and developing countries. Since Türkiye is situated in Eurasia, and positioned in Asia, between Eastern Europe and the Middle East, it exhibits similar cattle MM characteristics to these regions. Therefore, the CH<sub>4</sub> emissions resulting from MM were calculated according to these 3 regions, whereas developing country values for small ruminants and poultry were employed. Since the average yearly temperature for Kırklareli is 13.3°C as obtained from the Turkish Meteorology General Directorate (Anonymous, 2024e), the EF values were taken accordingly (Table 4, IPCC, 2006). Given that the cattle population is disaggregated by age in the available dataset, the averages of separately calculated annual CH<sub>4</sub> emission values for dairy and other cattle were used.

**Table 4. CH<sub>4</sub> EFs for MM (Tier 1), kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>**

|                     | Eastern Europe | Asia | Middle East |
|---------------------|----------------|------|-------------|
| Dairy cow (13°C)    | 14             | 11   | 2           |
| Other cattle (13°C) | 7              | 1    | 1           |
| Small ruminants*    |                | 0.1  |             |
| Poultry*            |                | 0.01 |             |

\*: developing countries for &lt;15°C

Eastern Europe: Solid-based systems are used for the majority of manure. About one-third of livestock manure is managed in liquid-based systems. Asia: About half of the cattle manure is used for fuel with the remainder managed in dry systems. Middle East: Over two-thirds of cattle manure is deposited on pastures and ranges (IPCC, 2006).

**Tier 2 Approach**

Since site-specific data, such as livestock population characterization, volatile solid matter (VSM) ratios, and methane yields, are obtainable for CH<sub>4</sub> emission estimation from livestock manure in Kırklareli, the IPCC (2006) Tier 2 approach is applied. Methane conversion factor (MCF) and MM systems (MS) usage data were taken from the IPCC Guidelines (2006) for the Eastern Europe, Asia, and Middle East Regions due to the similar values for the related parameters given in studies in the literature (Peypazar and Kılıç, 2021, Süslü and Seyfi, 2016; Öztürk, 2009). MM methane EFs for cattle were calculated by Eq. (1) as given in the IPCC Guideline (2006). Due to the cattle population data being disaggregated by age in the available dataset, the averages of the separately calculated sum of MCFxMS values for dairy and other cattle by region were utilized, while values for small ruminants and poultry from developing countries were employed.

$$EF_i = (VS_i \times 365) \times [B_{o(i)} \times 0.67 \sum_{(s,k)} \frac{MCF_{s,k}}{100} \times MS_{(i,s,k)}] \quad (\text{Eq.1})$$

EF<sub>i</sub>: annual methane EF for livestock category i, kg CH<sub>4</sub> animal<sup>-1</sup> year<sup>-1</sup>; VS<sub>i</sub>: daily volatile solid excreted for livestock category i, kg dry matter animal<sup>-1</sup> day<sup>-1</sup>; 365: annual calculation value, days year<sup>-1</sup>; 0.67: conversion factor of m<sup>3</sup> CH<sub>4</sub> to kilograms CH<sub>4</sub>, kg m<sup>-3</sup>; B<sub>o</sub>: CH<sub>4</sub> generating capacity by livestock category i, m<sup>3</sup>CH<sub>4</sub> kg<sup>-1</sup> VS; MCF: CH<sub>4</sub> conversion factors for each MM system S by climate region k, %; Ms<sub>i,s,k</sub>: fraction of livestock category i's manure handled using MM system S in climate region k, dimensionless.

#### 2.4 Calculation of bio-methane potential from animal manure by AD

The AD process involves the biological oxidation of organic substrates by specific microorganisms under anaerobic conditions. Organic matter is converted into stable end products while producing biogas, which typically consists of 55-70% CH<sub>4</sub> and 25-45% CO<sub>2</sub>. This biogas has significant potential for electricity and heat generation. The main factors affecting bio-methane generation from animal manure are the amount of manure produced, which depends on the number of animals in each species and the waste production rate per animal, along with availability rates. Moreover, the quality and quantity of livestock manure vary depending on the type of animal, type of feed, size of the animal body, type of breeding, ratio of total and volatile solids, and seasonal keeping time. The annual manure generation amount varies depending on the animal species, categorized by the age of cattle as adult (older than 12 months) and young (younger than 12 months), small ruminants adult (older than 6 months) and young (younger than 6 months). In order to determine the amount of livestock manure, the ages of cattle and sheep were taken into consideration. The availability rates of manure generated by cattle, sheep, and poultry as well as CH<sub>4</sub> yields based on solid matter (SM) and VSM ratios were used to determine the amount of bio-methane. The daily amount of manure produced varies between 8-10% of the live weight, depending on the age of the cattle, the content of the ration fed, the way of raising it and the productivity of the cattle. The amount of manure produced for 70-630 kg cattle is 6-51 kg day<sup>-1</sup> (Anonymous, 2024f; Anonymous, 2024g). Daily manure production for cattle is accepted as: 15 kg head<sup>-1</sup> assuming a weight of approximately 188 kg for young; 35 kg head<sup>-1</sup>, assuming a weight of approximately 438 kg for an adult (Anonymous, 2024h). Sheep produce 4-5% of their average live weight per kg of wet manure per day, depending on the production period. Goats produce manure up to 5% of their body weight daily. Daily manure production for small ruminants is accepted as: 1.5 kg head<sup>-1</sup> assuming a weight of 30 kg for young; 2.5 kg head<sup>-1</sup> assuming a weight of 50 kg for an adult (Anonymous, 2024i; Anonymous, 2024j; Anonymous, 2024k). Based on the manure values received from the producers as 0.175 kg egg-laying chicken<sup>-1</sup>, 0.035 kg broiler-chicken<sup>-1</sup> day<sup>-1</sup> in the study of Baban et. al., (2001) an average daily value of 0.1 kg chicken<sup>-1</sup> day<sup>-1</sup> was taken in this study for poultry manure generation. The manure generation values taken as the basis for the study are compatible with those used in similar literature studies (Table 5).

In the study conducted by Aktaş et al., (2015) for Tekirdağ, the availability rates (AR) of animal waste, SM (solid matter) and VSM ratios, and CH<sub>4</sub> yields per unit VSM were obtained as a result of analysis in an accredited laboratory. Due to the similarity of animal waste generated in Kırklareli to Tekirdağ province, the same values were taken in this study for methane potential calculations from livestock manure. The values used in the calculations are given in Table 6. Assumptions regarding the rate of collectable wet waste are taken as 41% for small ruminants, 41% for cattle, and 99% for poultry, as the general average of 3 months of pasture months, which are the days spent outside, and 9 months of other months, which are the days spent indoors (Aktaş et al., 2015; DBFZ, 2011). The bio-methane potential that can be generated from livestock manure (BMPI) for all districts was calculated with BMPI, m<sup>3</sup>CH<sub>4</sub> year<sup>-1</sup> Eq. (2).

$$BMPI = \sum_{(i,j)} P_{ij} \times M_i \times AR_i \times SM_i \times VSM_i \times YL_i \quad (\text{Eq. 2})$$

i: livestock category; j: district; P: population, head; M: unit manure generation, ton year<sup>-1</sup>; AR: availability rate, %; SM: solid matter, %; VSM: volatile solid matter, %; YL: livestock manure CH<sub>4</sub> yield, m<sup>3</sup> CH<sub>4</sub> ton<sup>-1</sup> VSM

**Table 5. Unit manure generation values from the literature, kg head<sup>-1</sup> day<sup>-1</sup>**

| Cattle | Small ruminant | Poultry    | Reference                |
|--------|----------------|------------|--------------------------|
| 14-39  | -              | 0.155      | Tunçez ve Soylu, 2022    |
| 22.5   | 1.6            | 0.045      | Abdeshahian et al., 2016 |
| 10-20  | 2              | 0.080-0.10 | Avcıoğlu ve Türker, 2012 |
| 14.5   | -              | -          | Atelge, 2021             |
| 37.5   | 2              | 0.137      | DBFZ, 2011; Özer, 2017   |
| 43     | 2.4            | 0.180      | Köse, 2017               |

**Table 6: The parameters used for bio-methane calculations based on animal species**

| Animal Type     | Unit waste generation, ton animal <sup>-1</sup> year <sup>-1</sup> | Availability rate, AR, %* | Solid matter (SM), %* | Volatile solid matter (VSM), %* | Yl, CH <sub>4</sub> yield, m <sup>3</sup> CH <sub>4</sub> ton <sup>-1</sup> VSM* |
|-----------------|--------------------------------------------------------------------|---------------------------|-----------------------|---------------------------------|----------------------------------------------------------------------------------|
| Cattle          | 5.48/12.78 (young/adult)                                           | 41                        | 14                    | 62                              | 316                                                                              |
| Small ruminants | 0.55/0.91 (young/adult)                                            | 41                        | 36                    | 81                              | 324                                                                              |
| Poultry         | 0.1                                                                | 99                        | 25                    | 64                              | 436                                                                              |

\*: Aktaş et al., 2015

The amount of electrical energy that can be produced from the calculated bio-methane amount was calculated by using Eq. (3) (DBFZ 2011).

$$E_{pl} = B_{MPI} \times EEM \times \eta \quad (\text{Eq. 3})$$

$E_{pl}$ : livestock CH<sub>4</sub>-based net electricity generation potential in kWh year<sup>-1</sup>; EEM: energy equivalent of CH<sub>4</sub>, 9.97 kWh m<sup>-3</sup>CH<sub>4</sub>;  $\eta$ : cogeneration electricity production efficiency, 40%, (DBFZ 2011).

## 2.5 Calculation of bio-methane potential from agricultural residue by AD

The main factors affecting bio-methane generation from agricultural residue are the agricultural production for each crop type, the residue-to-product ratio, and the availability rates. To calculate the methane potential of agricultural residue, the methane potential was determined based on the amount of waste produced from the most commonly planted agricultural products in Kırklareli, which are wheat, barley, rye, oats, maize, rice and sunflower. The data in Table 7 was used to calculate the methane potential of these products (BMPa) using Eq. (4), and the net electrical energy that can be obtained with the cogeneration system was calculated using Eq. (5). Similarly to the bio-methane generation from animal manure, the availability of residue, VSM amounts and their corresponding methane yields were taken into account in assessing the bio-methane potential of agricultural residues. The residue-to-product ratio and availability data for the crops were taken from Başçetinçelik et. al., (2006), and the values are within the range of the values given in FAO (2016). VSM ratios and methane yields were taken from DBFZ (2011), and sunflower values from Zhurka et. al., (2020). The values for wheat, barley, rice straw, and maize stalks are within the range of the results presented by the laboratory analysis study of Menardo et. al., (2012). The methane yield values for oat are within the range of the results presented by Murphy et. al., (2011).

**Table 7: The parameters used in bio-methane calculations based on plant species**

| Product type | Actual residue/product ratio | Availability rate (AR, %) | VSM % | Ya, CH <sub>4</sub> yield (m <sup>3</sup> CH <sub>4</sub> ton <sup>-1</sup> VSM) |
|--------------|------------------------------|---------------------------|-------|----------------------------------------------------------------------------------|
| Wheat        | 1.04                         | 15                        | 79.03 | 295.2                                                                            |
| Barley       | 1.08                         | 15                        | 76.13 | 351.9                                                                            |
| Rye          | 1.41                         | 15                        | 80.6  | 273.6                                                                            |
| Oat          | 1.00                         | 15                        | 76.13 | 290.5                                                                            |
| Maize        | 1.5                          | 60                        | 61.9  | 250.9                                                                            |
| Rice         | 1.5                          | 70                        | 76.13 | 260.5                                                                            |
| Sunflower    | 2.7                          | 60                        | 80.6  | 338*                                                                             |

\*: Zhurka et. al., 2020.

$$BMPa = \sum_{(x,j)} Pr_{xj} \times \left(\frac{R}{P}\right)_x \times AR_x \times VSM_x \times Ya_x \quad (\text{Eq.4})$$

BMPa, agricultural residue bio-methane potential,  $\text{m}^3\text{CH}_4 \text{ year}^{-1}$ ; x: cereal category; Pr: product value, ton/year; R/P: residue-to-product ratio; AR: availability rate, %; VSM: volatile solid matter (%); Ya: agricultural residue  $\text{CH}_4$  yield,  $\text{m}^3 \text{CH}_4 \text{ ton}^{-1} \text{ VSM}$ ;

$$\text{Epa} = \text{Mpa} \times \text{EEM} \times \eta \quad (\text{Eq.5})$$

Epa = agricultural residue methane-based net electricity generation potential in  $\text{kWh year}^{-1}$

### 3. Results and Discussion

#### 3.1 $\text{CH}_4$ emissions from enteric fermentation and MM

The  $\text{CH}_4$  emissions that occurred from enteric fermentation are calculated via the Tier 1 approach and given in Table 8 for three regions Eastern Europe, Asia and the Middle East. The  $\text{CO}_2$  equivalent ( $\text{CO}_{2\text{eq}}$ ) of  $\text{CH}_4$  emission was calculated by multiplying 28, which is the Global Warming Potential (GWP100) of  $\text{CH}_4$  over a 100-year time

**Table 8:  $\text{CH}_4$  emissions from enteric fermentation,  $\text{kg CH}_4 \text{ year}^{-1}$**

|                                                    | Animal numbers, head | Eastern Europe |          | Asia     |         | Middle East |         |
|----------------------------------------------------|----------------------|----------------|----------|----------|---------|-------------|---------|
|                                                    |                      | Average        |          | Average  |         | Average     |         |
| Dairy Cattle                                       | 152024               | 15050376       | 11933884 | 10337632 | 8741380 | 6993104     | 5852924 |
| Other Cattle                                       |                      | 8817392        |          | 7145128  |         | 4712744     |         |
| Small ruminants young and adult                    | 367778               | 1838890        |          | 1838890  |         | 1838890     |         |
| Total emission, $\text{kg CH}_4 \text{ year}^{-1}$ |                      | 13772774       |          | 10580270 |         | 7691814     |         |
| ton $\text{CO}_{2\text{eq}} \text{ year}^{-1}$     |                      | 385638         |          | 296248   |         | 215371      |         |

**Table 9:  $\text{CH}_4$  Tier 2 EFs for MM  $\text{kg CH}_4 \text{ head}^{-1} \text{ year}^{-1}$**

|                                    | Eastern Europe | Asia | Middle East |
|------------------------------------|----------------|------|-------------|
| Cattle young                       | 2.35           | 2.78 | 1.09        |
| Cattle adult                       | 5.49           | 6.49 | 2.54        |
| Small ruminants young and adult ** | 0.10           | 0.10 | 0.10        |
| Poultry**                          | 0.01           | 0.01 | 0.01        |

\*\* : developing countries for 13-14°C

**Table 10:  $\text{CH}_4$  emissions from MM,  $\text{kg CH}_4 \text{ year}^{-1}$**

|                              | Tier 1         |         |             | Tier 2         |        |             |
|------------------------------|----------------|---------|-------------|----------------|--------|-------------|
|                              | Eastern Europe | Asia    | Middle East | Eastern Europe | Asia   | Middle East |
| Dairy Cows                   | 2128336        | 1672264 | 304048      | -              | -      | -           |
| Other cattle                 | 1064168        | 152024  | 152024      | -              | -      | -           |
| Average*                     | 1596252        | 912144  | 228036      | -              | -      | -           |
| Cattle Young                 | -              | -       | -           | 102756         | 121603 | 47628       |
| Cattle adult                 | -              | -       | -           | 594328         | 703340 | 275476      |
| Small ruminants young**      |                |         |             | 574            | 574    | 574         |
| Small ruminants adult**      | 36778          | 36778   | 36778       | 36204          | 36204  | 36204       |
| Poultry**                    | 6840           | 6840    | 6840        | 6840           | 6840   | 6840        |
| Total                        | 1639870        | 955762  | 271654      | 740701         | 868561 | 366722      |
| ton $\text{CO}_{2\text{eq}}$ | 45916          | 26761   | 7606        | 20740          | 24320  | 10268       |

\*: average values of dairy and other cattle-originated  $\text{CH}_4$  emissions.

\*\* : developing countries for 13-14°C

horizon (Anonymous, 2024l). Enteric fermentation-based  $\text{CO}_2$  emissions are determined as 385638; 296248 and 215371 tons  $\text{CO}_{2\text{eq}} \text{ year}^{-1}$  for Eastern Europe, Asia and the Middle East, respectively which indicates Middle East value is the least. The methane EFs for MM from cattle, as calculated using Eq. (1), are provided in Table 9. The

CH<sub>4</sub> emissions from MM were calculated using the Tier 1 and Tier 2 approaches as presented in *Table 10*. Although the EFs for MM from the Tier 1 approach and the values calculated using the Tier 2 approach for various regions span a wide range (*Table 4* and *Table 9*), the EFs calculated using the Tier 2 approach for the Middle East are similar to those provided by the Tier 1 approach.

### 3.2 Methane and the electrical energy potential of animal manure

Based on the calculation principles outlined in the Methodology section, the available dry matter, corresponding methane, and net electricity potential by animal type for each district are calculated as specified by Equations 2 and 3 (*Table 11*). The distribution of energy potential across the districts is illustrated in *Figure 2*. *Figure 2* examines the distribution of animal manure-based energy potential in Kırklareli on a district basis. The Central district has the highest potential with 44422762 kWh year<sup>-1</sup> of net electrical energy, accounting for 33.86%, followed by the Lüleburgaz district with 33477984 kWh year<sup>-1</sup> representing 25.52%. The electrical energy potential of these two districts from animal waste constitutes 59.38%, more than half of the total potential of the province. Pehlivanköy has the lowest with a 1.68% share. In 2023, Kırklareli province had a total of 152024 cattle, 367778 sheep, and 684013 poultry. Cattle make up the largest share at 56%, followed by small ruminants at 39%, while poultry hold the smallest share at 5% in the CH<sub>4</sub> potential. The total CH<sub>4</sub> potential from animal manure is calculated to be 32895871 m<sup>3</sup> year<sup>-1</sup>, while the electrical energy corresponding to this potential is calculated to be 131188735 kWh year<sup>-1</sup>.

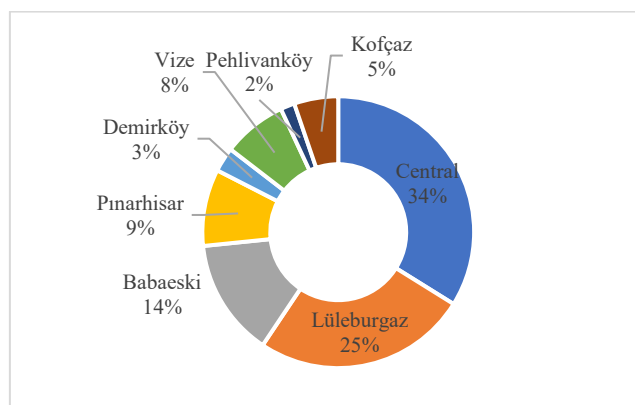


Figure 2. Distribution of animal manure-based energy potential by districts

Table 11. Kırklareli district-based animal methane and energy potential

| Districts    | Number of Animals |                 |               |                | Available dry matter<br>ton year <sup>-1</sup> | CH <sub>4</sub> Potential<br>m <sup>3</sup> year <sup>-1</sup> | Net Electrical Energy Potential<br>kWh year <sup>-1</sup> |
|--------------|-------------------|-----------------|---------------|----------------|------------------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------|
|              | Cattle            | Small ruminants | Poultry       | Total animals  |                                                |                                                                |                                                           |
| Central      | 45310             | 137998          | 327805        | 511113         | 34150                                          | 11139108                                                       | 44422762                                                  |
| Lüleburgaz   | 52369             | 50953           | 201919        | 305241         | 25982                                          | 8394680                                                        | 33477984                                                  |
| Babaeski     | 25202             | 38763           | 54244         | 118209         | 14347                                          | 4605027                                                        | 18364847                                                  |
| Pınarhisar   | 7279              | 55995           | 64821         | 128095         | 9222                                           | 3007629                                                        | 11994424                                                  |
| Vize         | 10919             | 31242           | 9323          | 51484          | 7836                                           | 2509715                                                        | 10008742                                                  |
| Kofçaz       | 4213              | 33394           | 15043         | 52650          | 5337                                           | 1725803                                                        | 6882501                                                   |
| Demirköy     | 4213              | 12915           | 3943          | 21071          | 2997                                           | 960596                                                         | 3830856                                                   |
| Pehlivanköy  | 2519              | 6518            | 6915          | 15952          | 1718                                           | 553315                                                         | 2206620                                                   |
| <b>Total</b> | <b>152024</b>     | <b>367778</b>   | <b>684013</b> | <b>1203815</b> | <b>101590</b>                                  | <b>32895871</b>                                                | <b>131188735</b>                                          |

### 3.3 Methane and the electrical energy potential of agricultural residues

Using the production data by cereal types given in *Table 2* and the values provided in *Table 7*, the CH<sub>4</sub> and electrical energy potential that can be generated from available agricultural residues were calculated as specified by Equations 4 and 5. Annual residue are calculated according to the given methodology and the results are given

with Table 12, Table 13 and Table 14. Table 14 gives the net electrical energy potential that can be generated from agricultural residues on a district basis. In Kırklareli province, a CH<sub>4</sub> potential of 109026520 m<sup>3</sup> year<sup>-1</sup> was calculated from agricultural residues consisting of a total of 1072149 tons year<sup>-1</sup> residue for 2023. The electrical energy value corresponding to this potential is calculated as 434797762 kWh year<sup>-1</sup>. Sunflower-originated CH<sub>4</sub> potential ranks first with 84033709 tons year<sup>-1</sup> (77%), while wheat follows with 15768806 tons year<sup>-1</sup> (14.5%). When the districts are examined in terms of bio-methane energy potential, Lüleburgaz district has the highest energy potential, with 132006087 kWh year<sup>-1</sup> accounting for 30.36%. It is followed by the Central district with, 128510689 kWh year<sup>-1</sup> representing 29.56%. The energy potential of these two districts from agricultural waste constitutes approximately 60%, more than half of the total potential of the province, depending on total production and corresponding residue. Demirköy has the smallest share, with 0.01% (Figure 3).

**Table 12. Annual agricultural residues by district, ton year<sup>-1</sup>**

|              | Wheat         | Barley       | Rye         | Oat         | Maize        | Rice         | Sunflower     | Total          |
|--------------|---------------|--------------|-------------|-------------|--------------|--------------|---------------|----------------|
| Central      | 73687         | 6036         | 860         | 1897        | 44027        | 0            | 154216        | <b>280723</b>  |
| Lüleburgaz   | 150875        | 9400         | 17          | 151         | 1326         | 1829         | 165549        | <b>329146</b>  |
| Babaeski     | 118362        | 5463         | 195         | 130         | 6591         | 11183        | 91454         | <b>233378</b>  |
| Pınarhisar   | 33452         | 1782         | 198         | 285         | 402          | 0            | 37155         | <b>73274</b>   |
| Demirköy     | 163           | 95           | 0           | 89          | 0            | 0            | 0             | <b>346</b>     |
| Vize         | 46318         | 1868         | 0           | 250         | 190          | 0            | 41813         | <b>90439</b>   |
| Pehlivanköy  | 16544         | 422          | 0           | 132         | 290          | 8810         | 13483         | <b>39680</b>   |
| Koçaz        | 11186         | 971          | 30          | 2543        | 0            | 0            | 10433         | <b>25163</b>   |
| <b>Total</b> | <b>450586</b> | <b>26037</b> | <b>1299</b> | <b>5477</b> | <b>52826</b> | <b>21821</b> | <b>514103</b> | <b>1072149</b> |

**Table 13. Annual agricultural residues methane potential by district, m<sup>3</sup> CH<sub>4</sub> year<sup>-1</sup>**

| Districts    | Wheat           | Barley         | Rye          | Oat           | Maize          | Rice           | Sunflower       | Total CH <sub>4</sub> , m <sup>3</sup> |
|--------------|-----------------|----------------|--------------|---------------|----------------|----------------|-----------------|----------------------------------------|
| Central      | 2578779         | 242542         | 28428        | 62913         | 4103956        | 0              | 25207728        | 32224345                               |
| Lüleburgaz   | 5280045         | 377696         | 561          | 5017          | 123582         | 253821         | 27060101        | 33100824                               |
| Babaeski     | 4142212         | 219534         | 6452         | 4324          | 614390         | 1552287        | 14948805        | 21488004                               |
| Vize         | 1620950         | 75081          | 0            | 8285          | 17735          | 0              | 6834572         | 8556623                                |
| Pınarhisar   | 1170684         | 71621          | 6546         | 9440          | 37440          | 0              | 6073311         | 7369042                                |
| Pehlivanköy  | 578965          | 16954          | 0            | 4390          | 27025          | 1222881        | 2203860         | 4054076                                |
| Koçaz        | 391470          | 39011          | 982          | 84368         | 0              | 0              | 1705331         | 2221162                                |
| Demirköy     | 5700            | 3806           | 0            | 2938          | 0              | 0              | 0               | 12444                                  |
| <b>Total</b> | <b>15768806</b> | <b>1046245</b> | <b>42969</b> | <b>181674</b> | <b>4924127</b> | <b>3028990</b> | <b>84033709</b> | <b>109026520</b>                       |

**Table 14. Annual agricultural residues net electrical energy potential by district, kWh year<sup>-1</sup>**

| Districts    | Wheat           | Barley         | Rye           | Oat           | Maize           | Rice            | Sunflower        | Total kWh        |
|--------------|-----------------|----------------|---------------|---------------|-----------------|-----------------|------------------|------------------|
| Lüleburgaz   | 21056820        | 1506253        | 2238          | 20008         | 492844          | 1012239         | 107915684        | 132006087        |
| Central      | 10284170        | 967259         | 113370        | 250896        | 16366575        | 0               | 100528420        | 128510689        |
| Babaeski     | 16519142        | 875500         | 25732         | 17244         | 2450187         | 6190520         | 59615834         | 85694160         |
| Vize         | 6464348         | 299422         | 0             | 33040         | 70727           | 0               | 27256274         | 34123811         |
| Pınarhisar   | 4668688         | 285624         | 26105         | 37648         | 149313          | 0               | 24220363         | 29387740         |
| Pehlivanköy  | 2308914         | 67612          | 0             | 17507         | 107775          | 4876851         | 8788995          | 16167653         |
| Koçaz        | 1561184         | 155575         | 3916          | 336458        | 0               | 0               | 6800861          | 8857994          |
| Demirköy     | 22734           | 15178          | 0             | 11715         | 0               | 0               | 0                | 49627            |
| <b>Total</b> | <b>62886000</b> | <b>4172423</b> | <b>171360</b> | <b>724517</b> | <b>19637420</b> | <b>12079610</b> | <b>335126431</b> | <b>434797762</b> |



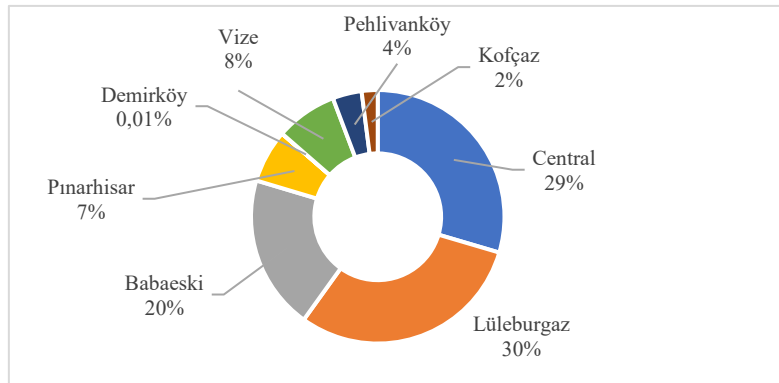


Figure 3. Agricultural residue-based energy potential distribution by district

### 3.4. Total energy potential of Kırklareli Province

The total CH<sub>4</sub> and energy potentials that can be generated from animal waste and agricultural residues of Kırklareli province for 2023 are presented in Table 15. The total methane potential of animal waste and agricultural residues was calculated to be 141922392 m<sup>3</sup>CH<sub>4</sub> year<sup>-1</sup>, while the total net electrical energy potential was calculated to be 565986497 kWh year<sup>-1</sup>. Upon examining the districts, it was revealed that the Central, Lüleburgaz, and Babaeski districts have the highest total electricity potential generated from animal manure and agricultural residues. 78.2% of Kırklareli's total methane potential for 2023 belongs to the Central, Lüleburgaz, and Babaeski districts. This high percentage suggests that investments should be concentrated near these districts. Figure 4 illustrates the total methane potential from animal waste and agricultural residues by the districts. In all districts except the Demirköy, the methane potential generated from agricultural residues is higher than that from animal manure.

Table 15 The total CH<sub>4</sub> and electrical energy potentials of Kırklareli by the districts in 2023

|              | Total CH <sub>4</sub> Potential, m <sup>3</sup> year <sup>-1</sup> | Total electricity, kWh year <sup>-1</sup> |
|--------------|--------------------------------------------------------------------|-------------------------------------------|
| Central      | 43363453                                                           | 172933451                                 |
| Lüleburgaz   | 41495504                                                           | 165484071                                 |
| Babaeski     | 26093031                                                           | 104059006                                 |
| Vize         | 11066337                                                           | 44132553                                  |
| Pınarhisar   | 10376671                                                           | 41382164                                  |
| Pehlivan köy | 4607391                                                            | 18374274                                  |
| Kofçaz       | 3946965                                                            | 15740495                                  |
| Demirköy     | 973040                                                             | 3880483                                   |
| Total        | 141922392                                                          | 565986497                                 |

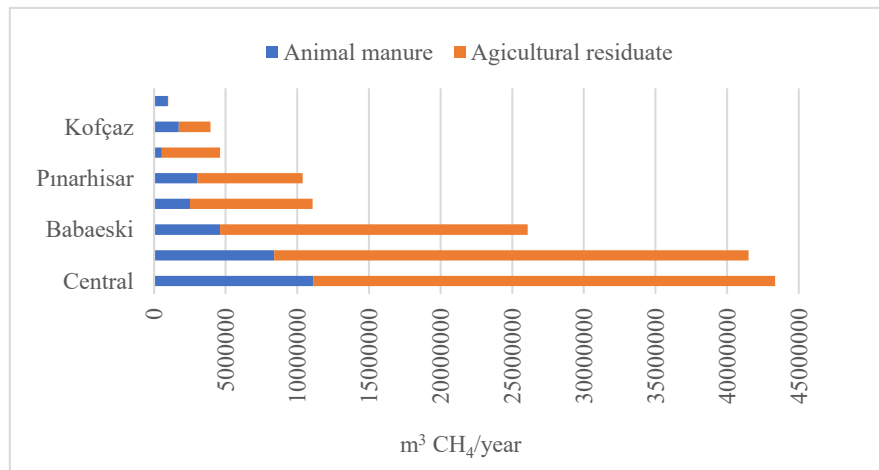


Figure 4. CH<sub>4</sub> potential distribution by districts

### 3.5. The calculation of CO<sub>2</sub> emission reduction obtained by AD biogas system

The CO<sub>2</sub> emissions resulting from the combustion of bio-methane generated through AD of animal manure and agricultural residue for energy production were calculated as 261492 tons CO<sub>2</sub> year<sup>-1</sup> using Eq. (6). The calculations were based on the stoichiometric ratio of 2.75 kg CO<sub>2</sub> produced per kg of CH<sub>4</sub>.

$$ECO_2 = MV * 0.67 * 2.75/1000 \quad (\text{Eq. 6})$$

ECO<sub>2</sub>: ton CO<sub>2</sub> year<sup>-1</sup>, MV: methane volume, m<sup>3</sup> year<sup>-1</sup>, 0.67: conversion factor of m<sup>3</sup> CH<sub>4</sub> to kilograms CH<sub>4</sub>, kg m<sup>-3</sup>; 2.75: stoichiometric ratio kg CO<sub>2</sub> formation per kg CH<sub>4</sub>

The GHG-reduction effect of biogas generation depends on two factors; mitigation of emissions occurred from MM and reducing emissions by substitution of fossil fuels.

The most significant benefit of a biogas generation system is that it prevents uncontrolled methane emissions. The CO<sub>2eq</sub> emissions from MM were calculated as outlined in the IPCC (2006) for both Tier 1 EFs and Tier 2 EFs given in Table 9 for 3 regions. The electricity generation capacity of CH<sub>4</sub> will replace the existing fossil fuel-based electricity in the national grid hence, the equivalent emission avoidance from biogas-based electricity generation was estimated using EFs of 1.165 and 0.998 tCO<sub>2eq</sub> MWh<sup>-1</sup> for lignite and hard coal, respectively (Anonymous, 2024m). Accordingly, the CO<sub>2</sub> emission mitigation capacity is determined to be between 310969-443799 tons CO<sub>2eq</sub> year<sup>-1</sup> based on the IPCC (2006) Eastern Europe, Asia, and Middle East Tier 1 and Tier 2 values (Table 16). Since the evaluation of CO<sub>2</sub> emission reduction was the main goal of the study CH<sub>4</sub> emissions from enteric fermentation were not taken into account. Total CO<sub>2eq</sub> emission reduction was determined according to the difference between the sum of the CO<sub>2eq</sub> emissions released through MM and the CO<sub>2</sub> emissions resulting from the same electricity generation from lignite or hard coal between the CO<sub>2</sub> emissions resulting from the combustion of bio-methane (Eq. 7).

$$ERCO_2 = [(MMCO_{2eq} + EECO_{2(coal)}) - EECO_{2(BMT)}] \quad (\text{Eq.7})$$

ERCO<sub>2</sub>: CO<sub>2</sub> emission reduction, ton year<sup>-1</sup>; MMCO<sub>2</sub>: CO<sub>2</sub> emissions from MM; EECO<sub>2(coal)</sub>: CO<sub>2</sub> emissions from electricity production through lignite or hard coal; EECO<sub>2(BMT)</sub>: CO<sub>2</sub> emissions from electricity production through bio-methane

**Table 16. The CO<sub>2eq</sub> emissions, ton year<sup>-1</sup>**

| MM     |                   | EE <sub>coal</sub> * |           | Total CO <sub>2eq</sub> Emissions from<br>MM + EE <sub>coal</sub> |           | EE <sub>BMT</sub> * | Reduction |           |
|--------|-------------------|----------------------|-----------|-------------------------------------------------------------------|-----------|---------------------|-----------|-----------|
|        | CO <sub>2eq</sub> | Lignite              | Hard Coal | Lignite                                                           | Hard Coal | AD                  | Lignite   | Hard Coal |
| Tier 1 | Eastern Europe    | 45916                |           | 705291                                                            | 610771    |                     | 443799    | 349279    |
|        | Asia              | 26761                |           | 686136                                                            | 591616    |                     | 424644    | 330124    |
|        | Middle East       | 7606                 |           | 666981                                                            | 572461    |                     | 405489    | 310969    |
|        | Eastern Europe    | 20740                | 659374    | 669643                                                            | 575123    | 261492              | 408150    | 313631    |
| Tier 2 | Asia              | 24320                |           | 683694                                                            | 589174    |                     | 422202    | 327682    |
|        | Middle East       | 10268                |           | 680114                                                            | 585594    |                     | 418622    | 324102    |

\*:EE: electricity emissions

## 4. Conclusions

According to the Türkiye National Energy Plan, the share of renewable energy in primary energy sources, which was 16.7% in 2020, is anticipated to rise to 23.7% by 2035 (ETKB, 2022). Biogas facilities, such as the one in Kırklareli, could significantly contribute to renewable energy production and support Türkiye in meeting its national climate change mitigation targets. Biogas systems support the circular economy and sustainable

production via the provision of energy and organic fertilizer. By integrating agricultural and livestock production with energy generation across Türkiye, the country's entire biomass potential can be effectively harnessed as an energy source. While methane potentials fluctuate annually due to changes in livestock numbers and agricultural output, the effective use of these existing potentials can be maximized through a comprehensive plan that encompasses both agricultural and livestock production alongside energy production. Aligning agricultural and livestock production with energy generation through proper planning will promote the use of sustainable energy. By supporting the livestock and agriculture sectors with comprehensive planning, enhancing the potential of renewable energy sources, and facilitating the transition to a circular economy, Türkiye can achieve compliance with the Paris Agreement and the EU Green Deal to address the climate crisis. This approach will contribute to environmental protection, reduce greenhouse gas emissions, and support sustainable development in the country. By setting agricultural and livestock production goals that also consider their waste as an energy source, a continuous and stable supply of energy can be achieved, rather than relying on variable values that fluctuate each year. Consequently, biomass can evolve from a mere potential to a consistently utilized energy source.

#### **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

#### **Conflicts of Interest**

The author declares that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

#### **Authorship Contribution Statement**

Concept: Özer, B.; Design: Özer, B.; Data Collection or Processing: Özer, B.; Statistical Analyses: Özer, B.; Literature Search: Özer, B.; Writing, Review and Editing: Özer, B.

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**Determination of Plant Nutrition Capacities of Agricultural Areas by Soil Analysis:  
Example of Süleymanpaşa District of Tekirdağ Province**

Tarım Alanlarının Bitki Besleme Kapasitelerinin Toprak Analizleri ile Belirlenmesi: Tekirdağ İli Süleymanpaşa İlçesi Örneği

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**Abstract**

Soil is one of the most important components of agricultural production. Therefore, healthy soils are increasingly needed for food security, nutrition goals and combating climate change. Soil health is critical to both ecosystem balance and human life. Soil not only supports plant growth, it also performs many important functions, from storing water to sequestering carbon. In addition, soil health is a critical factor not only for agriculture and food production but also for general environmental health, combating climate change and sustainable development. In this study, it was aimed to determine the sustainable productivity capacities by evaluating the analysis results of 60 soil samples taken from the fields in Süleymanpaşa district of Tekirdağ province, which were exposed to intense agricultural activities with wheat-sunflower rotation. The average pH, total salt, organic matter and lime contents of the samples taken were determined as 7.28, % 0.40, % 1.29 and % 3.62 respectively. It was determined that the majority of the soils (47 units) were in the "loam" texture class. The total N contents of the soil samples were determined as the lowest % 0.02 and the highest % 0.15. The average P, K, Ca, Mg, Fe, Mn, Zn and Cu contents of the soil samples were determined as 14.94, 211.68, 5393.15, 408.86, 13.60, 12.71, 0.88 and 1.05 mg kg<sup>-1</sup> respectively. When the average organic matter and total N contents in the samples were evaluated, it was determined that they had low levels of organic matter and total N contents. Considering the average values of the soil samples, it was determined that they were "high" in terms of Ca and Fe; "low" in terms of Mn and "sufficient" in terms of P, K, Mg, Zn and Cu. The biggest benefit of these studies is that, the correct use of fertilizer also has positive benefits in terms of economy and the environment. For this reason, organic fertilizers must be included in the fertilization programmes of soils with low organic matter.

**Keywords:** Soil analysis, Wheat, Sunflower, Organic Fertilizer, Soil productivity

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## Öz

Toprak, tarımsal üretimin en önemli bileşenlerinden biridir. Bu nedenle gıda güvenliği, beslenme hedefleri ve iklim değişikliğiyle mücadele için sağlıklı topraklara giderek daha fazla ihtiyaç duyulmaktadır. Toprak sağlığı, hem ekosistem dengesi hem de insan yaşamı için kritik bir öneme sahiptir. Toprak, sadece bitkilerin büyümesini desteklemekle kalmaz, aynı zamanda suyun depolanmasından karbon tutmaya kadar birçok önemli işlevi yerine getirmektedir. Bunun yanı sıra toprak sağlığı sadece tarım ve gıda üretimi için değil genel çevre sağlığı, iklim değişikliğiyle mücadele ve sürdürülebilir kalkınma için de kritik bir faktördür. Bu çalışmada, Tekirdağ ili Süleymanpaşa ilçesinde bulunan ve buğday-ayçiçeği ekim nöbetiyle yoğun tarımsal faaliyetlere maruz kalan tarlalardan alınan toplam 60 adet toprak örneğinin analiz sonuçları değerlendirilerek sürdürülebilir verimlilik kapasitelerinin belirlenmesi amaçlanmıştır. Alınan örneklerin ortalama pH, toplam tuz, organik madde ve kireç içerikleri sırasıyla 7.28, % 0.40, % 1.29 ve % 3.62 olarak belirlenmiştir. Toprakların büyük bir çoğunluğunun (47 adet) “tın” tekstür sınıfında olduğu tespit edilmiştir. Toprak örneklerinin toplam N içerikleri en düşük % 0.02 ve en yüksek % 0.15 olarak belirlenmiştir. Toprak örneklerinin ortalama P, K, Ca, Mg, Fe, Mn, Zn ve Cu içeriklerinin sırasıyla 14.94, 211.68, 5393.15, 408.86, 13.60, 12.71, 0.88 ve 1.05 mg kg<sup>-1</sup> olduğu tespit edilmiştir. Alınan örneklerdeki ortalama organik madde ve toplam N içerikleri değerlendirildiğinde düşük organik madde ve toplam N içeriklerine sahip olduğu saptanmıştır. Toprak örneklerine ait ortalama değerler dikkate alındığında Ca ve Fe bakımından “yüksek”; Mn bakımından “düşük”; P, K, Mg, Zn ve Cu bakımından “yeterli” düzeyde oldukları tespit edilmiştir. Bu çalışmaların en büyük faydası, doğru gübre kullanımının ekonomi ve çevre açısından da olumlu faydalarının bulunmasıdır. Özellikle bu çalışmadan da anlaşılan düşük organik madde içeren toprakların gübreleme programlarına mutlaka organik gübrelerin de dahil edilmesi gerçeğidir.

**Anahtar Kelimeler:** Toprak analizi, Buğday, Ayçiçeği, Organik Gübre, Toprak verimliliği

## 1. Introduction

In addition to the increasing population both in the world and in our country, we are faced with a major climate change. Climate change is among the causes of many natural events such as heavy and irregular rainfall, floods, inundations, extreme droughts, dust clouds, long-term frosts, storms, earthquakes, etc. For this reason, future plans should be made for agricultural production in line with these realities, and particular attention should be paid to preserving the productivity potential of soils (Bellitürk, 2019). It has been reported that there have been decreases in the organic matter, nutrient content and water holding capacity of soils, especially due to intensive use in recent years (Bellitürk, 2016; Aslam et al., 2020). One of the clearest examples of this is clearly seen in many regions of the Trakya Region, including the Süleymanpaşa district (Bellitürk and Sağlam, 2005; Bellitürk, 2011; Bellitürk, 2018; Büyükkiliz et al., 2022; Gürbüz and Bellitürk, 2021; Polat et al., 2019). It has been determined that the uncontrolled use of chemical fertilizers and agricultural pesticides to obtain the highest yield from a unit area has caused environmental pollution, contamination of underground water resources, and chemical residues in cultivated products have seriously threatened human and animal health (Kırımhan, 2005). Therefore, it is aimed to increase not only the productivity but also the cultivation of healthy products by protecting the soil with organic fertilizers obtained in completely natural ways that do not disturb the natural balance and are friendly to humans and the environment (Akan and Yanmaz, 2015; Demirkıran, 2021). One of the materials that will allow the soil to heal without disturbing its natural balance and away from chemical fertilizers is worm manure. With the spread of worm manure and the academic studies revealing its contributions to the soil and the environment, scientists have begun to call this situation the "organic green revolution" (Bellitürk, 2018). Organic earthworm, also known as vermicompost, is the product obtained as a result of the composting process of organic waste using earthworms. Vermicompost is a good organic fertilizer and an environmentally friendly production material with superior properties that can be easily used in organic agriculture (Bellitürk, 2016; Bellitürk and Çelik, 2021; Görres and Bellitürk, 2012).

According to *Table 1*, when the data for 2023 is taken into account, it is seen that the total chemical fertilizer used in our country is 7 million tons and the chemical fertilizer consumption of Tekirdağ province is 136 thousand tons. However, due to the low consumption of organic fertilizer, a clear figure can not be given. When we look at the long-term average of chemical fertilizer use in Tekirdağ province, it is seen that the highest consumption was recorded in 2016 as 210 thousand tons. It is stated in *Table 1* that the highest chemical fertilizer use in Türkiye was in 2020 with 7.1 million tons. It is thought that the fluctuations in the use of chemical fertilizers in our country in the last few years are due to reasons such as epidemics, economic recession, global energy crisis, etc. (Anonymous, 2024a).

**Table 1. The amount of chemical fertilizer consumed in Turkey and the amount of chemical fertilizer consumed in Tekirdağ province**

| Year | Chemical fertilizer consumption in Tekirdağ province (ton) | Chemical fertilizer consumption in Türkiye (ton) |
|------|------------------------------------------------------------|--------------------------------------------------|
| 2013 | 180 713                                                    | 5 813 612                                        |
| 2014 | 150 807                                                    | 5 471 518                                        |
| 2015 | 159 501                                                    | 5 507 779                                        |
| 2016 | 210 613                                                    | 6 744 922                                        |
| 2017 | 187 159                                                    | 6 332 872                                        |
| 2018 | 139 755                                                    | 5 411 881                                        |
| 2019 | 186 414                                                    | 6 087 714                                        |
| 2020 | 193 950                                                    | 7 143 144                                        |
| 2021 | 151 329                                                    | 6 480 101                                        |
| 2022 | 157 369                                                    | 5 902 539                                        |
| 2023 | 136 471                                                    | 7 030 779                                        |

The agricultural areas of Süleymanpaşa district for the last 5 years are given in *Table 2*, and population information is given in *Table 3* (Anonymous, 2024b). As can be seen, it is observed that there are increases in the

population rates in both Tekirdağ province and Süleymanpaşa district in 2022 and 2023, but there are some decreases in agricultural areas.

**Table 2. Agricultural areas of Tekirdağ province and Süleymanpaşa district**

| Year of production | Süleymanpaşa district agricultural area (da) | Tekirdağ province agricultural area (da) |
|--------------------|----------------------------------------------|------------------------------------------|
| 2019               | 711 952                                      | 3 911 723                                |
| 2020               | 715 731                                      | 3 927 950                                |
| 2021               | 759 318                                      | 4 154 336                                |
| 2022               | 759 446                                      | 4 153 674                                |
| 2023               | 759 182                                      | 4 153 457                                |

**Table 3. Population amounts of Tekirdağ province and Süleymanpaşa district**

| Year | Population of Süleymanpaşa district | Population of Tekirdağ province |
|------|-------------------------------------|---------------------------------|
| 2019 | 204 001                             | 1 055 412                       |
| 2020 | 203 617                             | 1 081 065                       |
| 2021 | 210 547                             | 1 113 400                       |
| 2022 | 215 558                             | 1 142 451                       |
| 2023 | 219 230                             | 1 167 059                       |

The planted area, yield and production amounts for wheat, sunflower and canola plants, which have been intensively planted in the last 5 years in Süleymanpaşa district, are shown in *Tables 4,5 and 6*, respectively (Anonymous, 2024b). Especially when *Tables 4 and 5* are examined, it is seen that there are decreases in wheat and sunflower yields and production quantities in the last 2 years (2022 and 2023). It is understood that this decrease is due to reasons other than the decrease in cultivated areas. Many human-induced factors, especially the increase in greenhouse gases in the atmosphere, the destruction of forests and industrial activities, accelerate climate change and drought. In addition, these reasons include the decrease in the amount of chemical fertilizer use due to drought caused by climate change and the increasing prices of chemical fertilizers due to the energy crisis (*Table 1*). While chemical fertilizer consumption in Turkey was 7.1 million tons in 2020, it decreased to 6.4 million tons in 2021 and 5.9 million tons in 2022. A similar situation emerges when the data for Tekirdağ province is examined.

When *Table 4* is examined, it is seen that despite the increase in the wheat planting areas especially in Süleymanpaşa district in 2023, there is a serious decrease in wheat yield and production amount. One of the most important reasons for this decrease is thought to be the drought caused by climate change in recent years and the increase in chemical fertilizer prices as a result of increasing energy costs, as shown in *Table 1*.

**Table 4. Wheat planting areas, yield and production amounts in Tekirdağ province Süleymanpaşa district**

| Year of production | Planting area (da) | Yield (kg/da) | Amount of production (ton) |
|--------------------|--------------------|---------------|----------------------------|
| 2019               | 347 039            | 433           | 150 382                    |
| 2020               | 355 366            | 375           | 133 409                    |
| 2021               | 351 927            | 554           | 194 902                    |
| 2022               | 357 588            | 438           | 156 461                    |
| 2023               | 361 548            | 355           | 128 249                    |

While the wheat and sunflower plants, which are intensively cultivated in the Süleymanpaşa district, are planted at one-year intervals, some producers also plant canola as an alternative to wheat. However, it is clearly understood from the data given in *Table 6* that canola planting areas have decreased significantly in recent years and that this decrease has caused a decrease of more than % 50 in production quantities. Therefore, it is likely that the effects of climate change on plants will affect agricultural activities in the future. Factors such as climate conditions, water and temperature can put pressure on product quality and thus affect production potential. In this respect, one of the basic elements of regional agricultural production suitability is climate (Holzkaemper et al., 2011).

One of the most important problems of the agricultural soils of the Trakya Region today is that they contain "low organic matter". In many previous studies on the agricultural soils of the Trakya Region, it was stated that the organic matter was insufficient and in some studies even % 80-85 of the soils had low organic matter content (Bellitürk, 2019). In this study, soil samples taken from 60 different points representatively from Süleymanpaşa district of Tekirdağ province were analyzed and the results were evaluated considering scientific data. In this regard, the objective of the research is to ascertain the present productivity capacity and agricultural sustainability of the Süleymanpaşa district.

**Table 5. Sunflower planting areas, yield and production amounts in Tekirdağ province Süleymanpaşa district**

| Year of production | Planting area (da) | Yield (kg/da) | Amount of production (ton) |
|--------------------|--------------------|---------------|----------------------------|
| 2019               | 256 417            | 230           | 58 989                     |
| 2020               | 268 824            | 245           | 65 990                     |
| 2021               | 313 101            | 250           | 78 251                     |
| 2022               | 318 822            | 193           | 61 589                     |
| 2023               | 327 199            | 112           | 36 779                     |

**Table 6. Canola planting areas, yield and production amounts in Süleymanpaşa district of Tekirdağ province**

| Year of production | Planting area (da) | Yield (kg/da) | Amount of production (ton) |
|--------------------|--------------------|---------------|----------------------------|
| 2019               | 41 599             | 320           | 13 312                     |
| 2020               | 21 100             | 320           | 6 752                      |
| 2021               | 22 500             | 369           | 8 300                      |
| 2022               | 10 000             | 315           | 3 150                      |
| 2023               | 4 400              | 308           | 1 353                      |

## 2. Materials and Methods

The soil samples used in this study were taken from 0-30 cm depth, when the final soil preparation was done before planting (before any fertilizer and pesticide application), from different villages and central locations of Süleymanpaşa district of Tekirdağ province and especially from areas where intensive agricultural production (wheat, sunflower, canola) was done (Table 7) using the zig-zag method. After being brought to the laboratory to be analyzed, it was air dried and then passed through a 2 mm sieve to make it ready for analysis (Jackson, 1958). The texture class of the soil samples was determined according to the percentage of saturation with water; the soil reaction was measured with a glass electrode pH meter at a ratio of 1:2.5 (soil:water) as recommended by the International Soil Science Association; the salt content was measured with an EC-meter and determined in percent (Lindsay and Norvell, 1978; Richards, 1954). Determination of lime amounts was done volumetrically with Scheibler calcimeter (Ülgen and Yurtsever, 1974). Organic matter in soils was determined by the Walkley-Black method (Sağlam, 2012). Available phosphorus was determined spectrophotometrically according to the Olsen method. Available Ca and Mg were determined by ICP-OES (DTPA), Fe, Mn, Cu and Zn contents were determined by the ICP-OES method (Lindsay and Norvell, 1978). Exchangeable K was determined in a flamephotometer (by extraction with ammonium acetate) (Jackson, 1958; Sağlam, 2012). In the evaluation of soil analyses, standard values specified in previous studies were used (FAO, 1990; Güneş et al., 1996; Güneş et al., 2010; Lindsay and Norvell, 1969; TOVEP, 1991). Information about the locations where soil samples were taken is shown in Table 7.

Located in the Thrace Region, Süleymanpaşa is the central district of Tekirdağ province. The districts of Muratlı and Hayrabolu are in the north, Çorlu in the east, Malkara in the west and Şarköy in the southwest. The Marmara Sea is in the south of the district (Figure 1 and 2). There are 78 neighborhoods in the district and its surface area is 1111 km<sup>2</sup>. Süleymanpaşa generally has a slightly rugged soil structure and it is possible to come across all shapes of the earth. The Mediterranean climate prevails on the Marmara coast of the district, while the continental climate prevails in the inner parts. The annual average temperature of Süleymanpaşa district is 13.9 °C and the annual average rainfall is 565 mm. Most of the precipitation occurs in the winter season (Anonymous, 2024c).



*Figure 1. Tekirdağ province map (Anonymous, 2024d)*

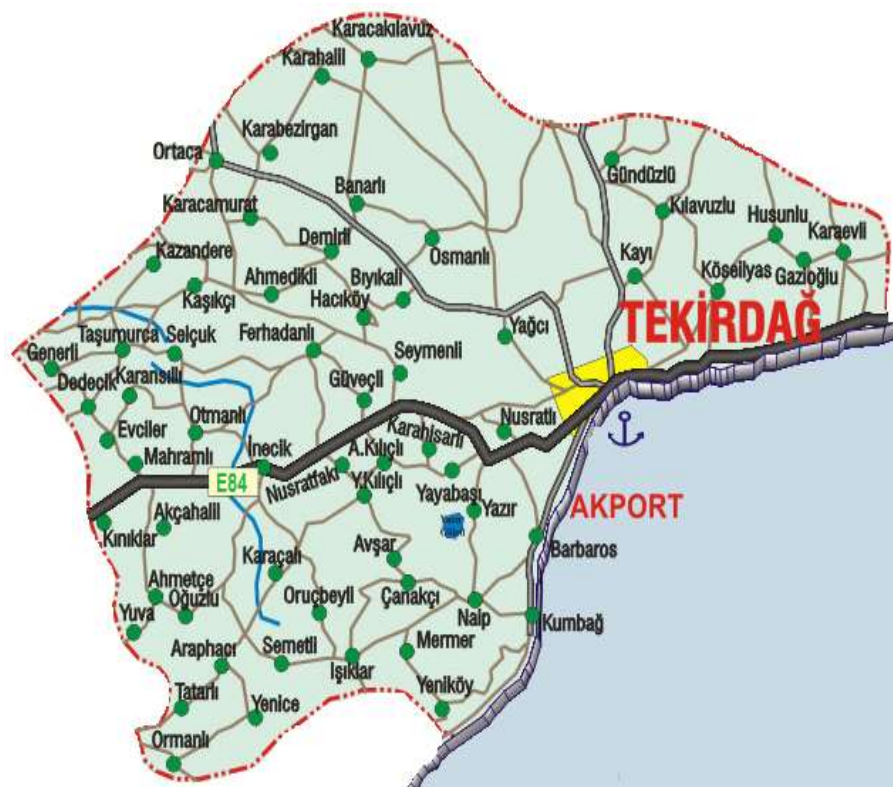


*Figure 2. Süleymanpaşa district map (Anonymous, 2024e)*

### 3. Results and Discussion

Some chemical and physical analysis results of the soil samples examined in the research region are given in *Table 7*.



Table 7. Some physical and chemical analysis results of soil samples

| Sample no | Neighborhoods belonging to the sampled places | pH (1:2.5) | Total salt (%) | Org. matter (%) | CaCO <sub>3</sub> (%) | Saturation |               |
|-----------|-----------------------------------------------|------------|----------------|-----------------|-----------------------|------------|---------------|
|           |                                               |            |                |                 |                       | (%)        | Texture class |
| 1         | Akçahalil                                     | 7.48       | 0.29           | 1.18            | 10.06                 | 53.00      | Clay Loam     |
| 2         | Akçahalil                                     | 7.61       | 0.26           | 0.86            | 1.86                  | 51.00      | Clay Loam     |
| 3         | Akçahalil                                     | 7.36       | 0.26           | 1.45            | 3.10                  | 48.00      | Loam          |
| 4         | Akçahalil                                     | 7.60       | 0.22           | 1.02            | 15.94                 | 49.00      | Loam          |
| 5         | Husunlu                                       | 7.33       | 0.30           | 1.90            | 2.91                  | 46.00      | Loam          |
| 6         | Husunlu                                       | 6.87       | 0.22           | 1.44            | 2.30                  | 46.00      | Loam          |
| 7         | Husunlu                                       | 6.78       | 0.25           | 1.17            | 2.45                  | 42.00      | Loam          |
| 8         | Husunlu                                       | 7.80       | 0.28           | 1.05            | 1.69                  | 42.00      | Loam          |
| 9         | Husunlu                                       | 7.24       | 0.19           | 1.14            | 1.86                  | 46.00      | Loam          |
| 10        | Husunlu                                       | 7.38       | 0.22           | 1.22            | 3.25                  | 48.00      | Loam          |
| 11        | Husunlu                                       | 7.52       | 0.30           | 1.00            | 8.60                  | 46.00      | Loam          |
| 12        | Husunlu                                       | 7.55       | 0.16           | 1.22            | 10.32                 | 46.00      | Loam          |
| 13        | Husunlu                                       | 7.15       | 0.14           | 1.04            | 2.32                  | 42.00      | Loam          |
| 14        | Husunlu                                       | 6.50       | 0.22           | 0.99            | 1.24                  | 40.00      | Loam          |
| 15        | Karahisarlı                                   | 6.91       | 0.67           | 0.48            | 1.84                  | 46.00      | Loam          |
| 16        | Karahisarlı                                   | 6.95       | 0.88           | 1.23            | 2.94                  | 42.00      | Loam          |
| 17        | Karahisarlı                                   | 7.21       | 0.84           | 3.11            | 1.70                  | 40.00      | Loam          |
| 18        | Karahisarlı                                   | 7.13       | 0.75           | 2.87            | 1.55                  | 38.00      | Loam          |
| 19        | Karahisarlı                                   | 7.33       | 0.69           | 1.08            | 1.55                  | 52.00      | Clay Loam     |
| 20        | Karahisarlı                                   | 7.13       | 0.84           | 2.22            | 1.55                  | 35.00      | Loam          |
| 21        | Karahisarlı                                   | 7.21       | 0.81           | 0.94            | 1.24                  | 43.00      | Loam          |
| 22        | Karaevli                                      | 7.64       | 0.16           | 0.66            | 6.13                  | 51.00      | Clay Loam     |
| 23        | Karaevli                                      | 7.34       | 0.18           | 0.80            | 1.69                  | 49.00      | Loam          |
| 24        | Karaevli                                      | 7.61       | 0.15           | 0.49            | 7.66                  | 45.00      | Loam          |
| 25        | Karaevli                                      | 7.55       | 0.11           | 1.16            | 1.38                  | 52.00      | Clay Loam     |
| 26        | Karaevli                                      | 7.57       | 0.15           | 0.80            | 4.90                  | 51.00      | Clay Loam     |
| 27        | Karaevli                                      | 7.63       | 0.14           | 0.88            | 6.28                  | 49.00      | Loam          |
| 28        | Karaevli                                      | 7.43       | 0.35           | 1.15            | 12.56                 | 44.00      | Loam          |
| 29        | Karaevli                                      | 7.44       | 0.13           | 1.14            | 1.84                  | 45.00      | Loam          |
| 30        | Karaevli                                      | 6.62       | 0.09           | 1.55            | 1.53                  | 46.00      | Loam          |
| 31        | Karaevli                                      | 7.56       | 0.19           | 1.37            | 1.38                  | 40.00      | Loam          |
| 32        | Karaevli                                      | 7.52       | 0.18           | 1.45            | 1.23                  | 46.00      | Loam          |
| 33        | Karaevli                                      | 7.47       | 0.17           | 1.56            | 2.60                  | 52.00      | Clay Loam     |
| 34        | Karaevli                                      | 7.14       | 0.16           | 1.78            | 0.93                  | 54.00      | Clay Loam     |
| 35        | Karaevli                                      | 7.58       | 0.16           | 1.34            | 2.60                  | 54.00      | Clay Loam     |
| 36        | Kayı                                          | 6.51       | 0.18           | 1.09            | 0.92                  | 44.00      | Loam          |
| 37        | Kayı                                          | 7.44       | 0.16           | 1.24            | 2.45                  | 35.00      | Loam          |
| 38        | Kayı                                          | 7.58       | 0.13           | 1.11            | 3.98                  | 38.00      | Loam          |
| 39        | Kayı                                          | 7.62       | 0.20           | 1.15            | 1.69                  | 44.00      | Loam          |
| 40        | Kayı                                          | 7.40       | 0.14           | 1.48            | 1.53                  | 44.00      | Loam          |
| 41        | Kayı                                          | 7.52       | 0.34           | 0.91            | 7.97                  | 40.00      | Loam          |
| 42        | Kayı                                          | 6.31       | 0.14           | 1.16            | 1.38                  | 40.00      | Loam          |
| 43        | Yağcı                                         | 7.51       | 0.41           | 1.37            | 3.87                  | 49.00      | Loam          |
| 44        | Yağcı                                         | 7.10       | 0.62           | 1.83            | 1.08                  | 39.00      | Loam          |
| 45        | Yağcı                                         | 7.59       | 0.41           | 1.49            | 3.56                  | 54.00      | Clay Loam     |
| 46        | Yağcı                                         | 7.67       | 0.21           | 1.70            | 4.02                  | 51.00      | Clay Loam     |
| 47        | Yağcı                                         | 4.64       | 0.08           | 1.08            | 1.24                  | 32.00      | Loam          |

**Table 7. Some physical and chemical analysis results of soil samples (continued)**

| Sample no | Neighborhoods belonging to the sampled places | pH (1:2.5) | Total salt (%) | Org. matter (%) | CaCO <sub>3</sub> (%) | Saturation |               |
|-----------|-----------------------------------------------|------------|----------------|-----------------|-----------------------|------------|---------------|
|           |                                               |            |                |                 |                       | (%)        | Texture class |
| 48        | Yağcı                                         | 7.59       | 0.24           | 1.31            | 1.70                  | 48.00      | Loam          |
| 49        | Yağcı                                         | 7.61       | 0.22           | 1.20            | 3.41                  | 48.00      | Loam          |
| 50        | Yağcı                                         | 7.52       | 0.38           | 1.07            | 2.63                  | 46.00      | Loam          |
| 51        | Aşağıkılıçlı                                  | 7.05       | 0.78           | 1.68            | 1.08                  | 40.00      | Loam          |
| 52        | Aşağıkılıçlı                                  | 7.31       | 2.15           | 1.12            | 4.64                  | 40.00      | Loam          |
| 53        | Aşağıkılıçlı                                  | 7.55       | 0.63           | 1.35            | 10.06                 | 42.00      | Loam          |
| 54        | Aşağıkılıçlı                                  | 6.98       | 0.69           | 2.57            | 2.32                  | 38.00      | Loam          |
| 55        | Seymenli                                      | 7.53       | 0.43           | 1.33            | 9.44                  | 46.00      | Loam          |
| 56        | Seymenli                                      | 7.25       | 0.87           | 0.88            | 1.70                  | 42.00      | Loam          |
| 57        | Güveçli                                       | 7.24       | 1.98           | 1.31            | 5.11                  | 39.00      | Loam          |
| 58        | Güveçli                                       | 7.13       | 0.94           | 0.83            | 1.55                  | 47.00      | Loam          |
| 59        | Köseilyas                                     | 7.56       | 0.18           | 1.64            | 4.75                  | 52.00      | Clay Loam     |
| 60        | Köseilyas                                     | 7.60       | 0.16           | 0.62            | 1.99                  | 42.00      | Loam          |
| Min.      | -                                             | 4.64       | 0.08           | 0.48            | 0.92                  | 32.00      | -             |
| Mean      | -                                             | 7.28       | 0.40           | 1.29            | 3.62                  | 45.00      | -             |
| Max.      | -                                             | 7.80       | 2.15           | 3.11            | 15.94                 | 54.00      | -             |

Some macro and micro plant nutrient element statuses of soil samples are given in Table 8.

**Table 8. Some macro and micro plant nutrient element contents of soil samples**

| Sample no | N    | P     | K      | Ca      | Mg     | Fe                  | Mn    | Zn   | Cu   |
|-----------|------|-------|--------|---------|--------|---------------------|-------|------|------|
|           | %    |       |        |         |        | mg kg <sup>-1</sup> |       |      |      |
| 1         | 0.06 | 5.17  | 221.00 | 7278.00 | 250.10 | 12.45               | 12.27 | 0.24 | 1.01 |
| 2         | 0.04 | 4.35  | 200.00 | 4435.00 | 691.00 | 19.42               | 12.55 | 0.26 | 1.76 |
| 3         | 0.07 | 3.54  | 215.90 | 5898.00 | 389.80 | 18.78               | 20.37 | 0.34 | 1.32 |
| 4         | 0.05 | 7.08  | 186.50 | 6301.00 | 89.72  | 9.95                | 10.02 | 0.25 | 0.85 |
| 5         | 0.09 | 10.55 | 218.70 | 3795.00 | 199.20 | 6.58                | 7.95  | 0.29 | 0.98 |
| 6         | 0.07 | 2.95  | 199.00 | 6146.00 | 413.90 | 26.14               | 14.31 | 0.71 | 0.72 |
| 7         | 0.06 | 16.53 | 215.80 | 6549.00 | 547.40 | 40.53               | 18.07 | 0.60 | 0.99 |
| 8         | 0.05 | 4.28  | 211.50 | 5571.00 | 539.70 | 50.64               | 19.76 | 0.60 | 1.09 |
| 9         | 0.06 | 8.86  | 98.85  | 2288.00 | 344.70 | 9.01                | 11.41 | 2.20 | 0.87 |
| 10        | 0.06 | 4.21  | 105.40 | 5236.00 | 371.20 | 7.38                | 7.82  | 2.52 | 0.90 |
| 11        | 0.05 | 1.92  | 60.67  | 5364.00 | 161.30 | 4.43                | 4.85  | 0.35 | 0.54 |
| 12        | 0.06 | 7.82  | 159.80 | 4249.00 | 148.60 | 4.39                | 6.42  | 0.58 | 1.12 |
| 13        | 0.05 | 8.49  | 76.55  | 1758.00 | 389.30 | 7.69                | 9.98  | 6.28 | 0.84 |
| 14        | 0.05 | 11.88 | 33.04  | 733.40  | 163.80 | 17.83               | 19.65 | 5.16 | 1.84 |
| 15        | 0.02 | 8.12  | 186.30 | 5735.00 | 527.20 | 15.60               | 17.71 | 0.18 | 1.58 |
| 16        | 0.06 | 15.28 | 182.10 | 5395.00 | 461.50 | 10.98               | 12.61 | 0.39 | 1.14 |
| 17        | 0.15 | 77.93 | 367.40 | 4604.00 | 545.10 | 14.20               | 13.19 | 3.54 | 1.56 |
| 18        | 0.14 | 93.95 | 395.40 | 4077.00 | 491.70 | 12.70               | 10.76 | 4.31 | 1.49 |
| 19        | 0.05 | 3.10  | 184.40 | 6238.00 | 568.20 | 14.82               | 13.06 | 0.28 | 1.53 |
| 20        | 0.11 | 81.11 | 394.30 | 4432.00 | 473.90 | 13.69               | 12.14 | 2.97 | 1.22 |
| 21        | 0.05 | 3.84  | 188.20 | 5380.00 | 566.10 | 13.41               | 13.10 | 0.21 | 1.48 |
| 22        | 0.03 | 5.98  | 208.30 | 7926.00 | 461.80 | 8.13                | 7.87  | 0.53 | 0.51 |
| 23        | 0.04 | 4.50  | 260.70 | 73.17   | 500.20 | 11.62               | 18.21 | 0.61 | 1.05 |
| 24        | 0.02 | 10.62 | 195.60 | 7994.00 | 403.00 | 8.42                | 7.16  | 0.40 | 0.52 |
| 25        | 0.06 | 9.44  | 167.00 | 7214.00 | 352.20 | 12.94               | 12.28 | 0.24 | 0.88 |
| 26        | 0.04 | 12.77 | 236.70 | 7948.00 | 242.20 | 10.26               | 9.01  | 0.29 | 0.72 |

**Table 8. Some macro and micro plant nutrient element contents of soil samples (continued)**

| Sample no | N %  | P      | K      | Ca      | Mg                  | Fe    | Mn    | Zn   | Cu   |
|-----------|------|--------|--------|---------|---------------------|-------|-------|------|------|
|           |      |        |        |         | mg kg <sup>-1</sup> |       |       |      |      |
| 27        | 0.04 | 3.69   | 201.20 | 8024.00 | 419.70              | 8.51  | 7.84  | 0.44 | 0.50 |
| 28        | 0.06 | 4.28   | 190.70 | 8099.00 | 234.30              | 9.12  | 10.20 | 0.27 | 0.67 |
| 29        | 0.06 | 13.80  | 110.60 | 4034.00 | 144.40              | 10.52 | 10.75 | 0.31 | 0.78 |
| 30        | 0.08 | 1.77   | 190.70 | 6528.00 | 567.20              | 16.88 | 23.58 | 0.47 | 1.09 |
| 31        | 0.07 | 6.86   | 225.70 | 5475.00 | 354.00              | 12.80 | 7.36  | 0.46 | 1.17 |
| 32        | 0.07 | 7.45   | 284.00 | 6473.00 | 399.70              | 18.48 | 8.52  | 0.50 | 1.25 |
| 33        | 0.08 | 12.69  | 279.10 | 8466.00 | 493.70              | 8.09  | 13.65 | 0.37 | 0.86 |
| 34        | 0.09 | 11.14  | 240.80 | 7140.00 | 425.30              | 13.42 | 16.82 | 0.47 | 0.93 |
| 35        | 0.07 | 12.32  | 241.70 | 8292.00 | 461.00              | 8.87  | 13.50 | 0.38 | 0.95 |
| 36        | 0.05 | 21.40  | 235.40 | 3517.00 | 549.20              | 14.46 | 19.74 | 0.09 | 1.26 |
| 37        | 0.06 | 15.42  | 259.50 | 4030.00 | 122.70              | 3.98  | 6.67  | 0.14 | 0.67 |
| 38        | 0.06 | 7.60   | 195.50 | 4639.00 | 158.40              | 3.78  | 4.11  | 0.03 | 0.61 |
| 39        | 0.06 | 7.31   | 165.70 | 5435.00 | 272.80              | 9.45  | 9.85  | 0.11 | 0.82 |
| 40        | 0.07 | 8.93   | 359.70 | 4462.00 | 211.90              | 6.29  | 10.77 | 0.15 | 0.99 |
| 41        | 0.05 | 13.95  | 234.30 | 4728.00 | 212.00              | 7.03  | 8.19  | 0.18 | 0.59 |
| 42        | 0.06 | 13.36  | 202.50 | 3464.00 | 574.60              | 16.69 | 29.85 | 0.13 | 1.20 |
| 43        | 0.07 | 9.82   | 181.00 | 6421.00 | 940.30              | 10.43 | 7.48  | 0.15 | 1.33 |
| 44        | 0.09 | 61.25  | 375.10 | 2718.00 | 331.20              | 8.65  | 9.14  | 2.87 | 0.83 |
| 45        | 0.08 | 11.07  | 169.20 | 6555.00 | 931.70              | 11.40 | 7.37  | 0.21 | 1.36 |
| 46        | 0.09 | 5.39   | 166.50 | 6583.00 | 889.70              | 15.41 | 9.24  | 0.18 | 1.31 |
| 47        | 0.05 | 12.69  | 129.30 | 972.40  | 210.70              | 68.48 | 67.65 | 0.32 | 1.06 |
| 48        | 0.07 | 1.85   | 152.70 | 3861.00 | 118.10              | 10.00 | 15.20 | 0.31 | 0.86 |
| 49        | 0.06 | 5.31   | 169.50 | 6625.00 | 937.30              | 14.05 | 7.29  | 0.23 | 1.37 |
| 50        | 0.05 | 10.11  | 164.30 | 6826.00 | 955.80              | 13.04 | 6.90  | 0.28 | 1.36 |
| 51        | 0.08 | 45.17  | 317.70 | 3425.00 | 389.10              | 10.97 | 9.77  | 2.71 | 1.04 |
| 52        | 0.06 | 5.09   | 138.40 | 5095.00 | 283.50              | 12.14 | 15.31 | 0.26 | 1.00 |
| 53        | 0.07 | 4.21   | 236.20 | 7672.00 | 207.10              | 9.11  | 6.64  | 0.32 | 1.26 |
| 54        | 0.13 | 101.40 | 405.90 | 4723.00 | 521.60              | 15.76 | 13.30 | 4.22 | 1.60 |
| 55        | 0.06 | 4.28   | 445.60 | 5392.00 | 148.90              | 6.65  | 4.99  | 0.25 | 0.78 |
| 56        | 0.04 | 8.19   | 193.00 | 6126.00 | 534.80              | 16.00 | 13.70 | 0.24 | 1.44 |
| 57        | 0.07 | 5.98   | 138.30 | 5321.00 | 294.80              | 14.57 | 17.79 | 0.35 | 1.10 |
| 58        | 0.04 | 11.37  | 188.30 | 5843.00 | 563.30              | 14.22 | 13.32 | 0.16 | 1.47 |
| 59        | 0.08 | 1.70   | 207.10 | 9301.00 | 220.20              | 9.45  | 8.28  | 0.40 | 0.64 |
| 60        | 0.03 | 5.02   | 136.20 | 4706.00 | 159.60              | 5.39  | 5.15  | 0.26 | 0.56 |
| Min.      | 0.02 | 1.70   | 33.04  | 73.17   | 89.72               | 3.78  | 4.11  | 0.03 | 0.50 |
| Mean      | 0.06 | 14.94  | 211.68 | 5393.15 | 408.86              | 13.60 | 12.71 | 0.88 | 1.05 |
| Max.      | 0.15 | 101.40 | 445.60 | 9301.00 | 955.80              | 68.48 | 67.65 | 6.28 | 1.84 |

As seen in Table 7, the lowest pH value was 4.64 in sample 47 and the highest pH value was 7.80 in sample 8. The average pH value of the soils was 7.28 (neutral). When the total salt values of the soil samples were analysed, it was determined that the lowest salt content was % 0.08 (sample no. 47) and the highest salt content was % 2.15 (sample no. 52) and they were medium saline soils. In terms of organic matter content, the highest value was determined as % 3.11 (soil no. 17) and the lowest value was determined as % 0.48 (soil no. 15) and the average was determined as 1.29 (less). In terms of lime (CaCO<sub>3</sub>) content, it was determined that the soils had an average of % 3.62 lime content and the textural classes were clay loam and loam soils. Similar results were obtained in Hayrabolu district of Tekirdağ province and the average pH, total salt, organic matter and lime contents of 26 soil samples were determined as 6.75, % 0.16, % 1.38 and % 1.98 respectively (Bellitürk and Çelik, 2023). In a study carried out to determine the nutrient status of agricultural soils in the Marmara Region of Turkey, where Tekirdağ province is located, it was reported that % 67.7 of the soils were very low and low in terms of organic matter

coverage and very poor and poor in terms of nitrogen, whereas % 7.2 of only 1752 soils were good or very good (Taşova and Akın, 2013). In this case, it can be considered that factors such as destruction of surface cover, deforestation, erosion as a result of continuous cultivation of soils for agricultural purposes prevent the accumulation of organic matter in the soils of the region.

Organic matter content in Turkish soils is generally low, thus limiting productivity. In this respect, different combinations of applications such as compost and vermicompost improve the physico-chemical properties of the soil and positively affect soil health and productivity. As a result of the application of vermicompost prepared from different substrates (cow manure, paper waste and rice straw) together with N:P:K, which is recommended for fertilizing soils poor in organic matter, it was determined that cow manure vermicompost increased soil health and product yield, and at the same time, products rich in Zn and Fe in wheat (Aslam et al., 2019) and N, P, K in grapes (Açıkbaz and Bellitürk, 2016) were obtained. In the studies conducted by Tavalı et al., (2014) and Çıtak et al., (2011), it was emphasized that the application of vermicompost to the soil increases the organic matter content of the soil. In addition, in the study conducted by Barlas et al. (2018) examining the effects of increasing vermicompost doses applied to soil and peat on the growth and development of wheat (*Triticum vulgare* L.) plants, it was determined that all vermicompost doses applied to the growing medium had a statistically significant effect on the nutritional status of the above-root organs of the plants.

When the soils were evaluated in terms of texture classes, it was determined that a total of 48 soils fell into the "loam (L)" texture class (FAO, 1990; Güneş et al., 1996; Güneş et al., 2010; Lindsay and Norwell, 1969; TOVEP, 1991). When the general physical and chemical properties of soils are examined, it is thought that there has been a gradual depletion of organic matter in the last 10 years, and this is due to conventional agriculture and planting with an emphasis on chemical fertilizers. Considering the parameters in *Table 8*, it was determined that the soils were in the "low" class and poor in terms of N with an average total N value of % 0.06. This may be due to N losses in the soil in gaseous form or through leaching. In most of the similar studies conducted on local soils, it was found that the soil samples were poor in terms of both organic matter and total N (Bellitürk, 2023; Bellitürk and Çelik, 2023; Büyükfiliz et al., 2022). The average P, K, Ca and Mg contents of the soil samples in terms of macro elements were determined to be 14.94 mg kg<sup>-1</sup>, 211.68 mg kg<sup>-1</sup>, 5393.15 mg kg<sup>-1</sup> and 408.86 mg kg<sup>-1</sup>, respectively. Accordingly, it was revealed that the soil samples were "sufficient" in terms of P, K and Mg and "excessive" in terms of Ca. According to the results of a similar study conducted by Gürbüz and Bellitürk (2021) in Ergene district, it was determined that % 69.57 of the 70 soils examined were in the 'low' class of total nitrogen % 55.07 were in the 'sufficient' class of available phosphorus, % 49.28 were in the 'sufficient' class of exchangeable potassium, % 42.03 were in the 'sufficient' class of exchangeable Ca, and % 57.97 were in the 'sufficient' class of exchangeable Mg. Considering the average micro element values, it was determined that Fe, Mn, Zn and Cu contents were in the 13.60 mg kg<sup>-1</sup> (excess), 12.71 mg kg<sup>-1</sup> (low), 0.88 mg kg<sup>-1</sup> (sufficient) and 1.05 mg kg<sup>-1</sup> (sufficient) classes, respectively. In similar studies conducted previously in the local soils, the emphasis on low organic matter comes to the fore (Bellitürk, 2011; Bellitürk, 2019; Büyükfiliz et al., 2022; Büyükfiliz et al., 2023; Gürbüz and Bellitürk, 2021; Polat et al., 2019).

Although it is one of the most important indicators of soil quality, the importance of soil organic matter is not sufficiently known in our country. This results in low fertilization efficiency and can lead to increased fertilizer input costs for producers and even pollution of the environment. In this respect, it is of great importance to pay attention to increasing the amount of organic matter in the soil, to use chemical fertilizers and organic fertilizers together, and to abandon agricultural systems that use only chemical fertilizers.

#### 4. Conclusions

As a result of the study in which the analysis results of a total of 60 soil samples taken from fields exposed to intensive agricultural activities with wheat-sunflower crop rotation in Süleymanpaşa district of Tekirdağ province were evaluated, it was determined that the average pH value of the samples taken was 7.28 (neutral), total salt content was % 0.40 (salt-free), organic matter amount was % 1.29 (low), total N content was % 0.06 (low) and lime content was % 3.62 (low calcareous) and the texture class was clayey loam and loamy soils. The average P, K, Ca, Mg, Fe, Mn, Zn and Cu contents of the soil samples were determined to be 14.94, 211.68, 5393.15, 408.86, 13.60, 12.71, 0.88 and 1.05 mg kg<sup>-1</sup>, respectively. Considering these values, it was determined that the soil samples were high in Ca and Fe; low in Mn; and sufficient in P, K, Mg, Zn and Cu.

Organic matter content is of great importance for the physical, chemical, biological properties and productivity potential of agricultural soils to be at the desired levels. In this respect, organic matter is widely accepted as a very important indicator of productivity in terms of sustainable soil management. Therefore, agricultural activities carried out on soils poor in organic matter must be taken into consideration and the use of organic fertilizers must be included in fertilization programs. Otherwise, soil fertility may decrease over time as a result of chemical fertilizer applications alone, and agricultural production may be at risk. Although it is known by everyone that excessive chemical fertilizer is used in the Süleymanpaşa district, agricultural production such as wheat and sunflower according to the correct fertilization programs will be very beneficial for the producers and the ecology. What is particularly understood from this study is that organic fertilizers must be included in the fertilization programs of soils with low organic matter content.

In countries like Turkey, where the population is increasing and agricultural lands are decreasing, it is very important to expand the use of organic fertilizers obtained by evaluating organic waste rather than those obtained from fossil fuels in the use of fertilizers among agricultural inputs. According to the results of this study, in which various findings were obtained on wheat, sunflower and partly canola farming in Süleymanpaşa district using intensive chemical fertilizers, it was revealed that fertilization programs should be made according to soil analysis results and that biological and/or organic fertilizers should definitely be included in the fertilization program in addition to chemical fertilizers. It is a known fact that in order to implement sustainable agriculture, the right type and amount of fertilizer must be used at the right time. It is of great importance that the inputs used in agricultural production are carried out in a controlled and planned manner in order to meet the needs of the increasing population, protect the environment and use natural resources without depletion. In this respect, this study, which revealed that the agricultural soils of Süleymanpaşa district are insufficient in terms of organic matter, should be carried out every year in a more comprehensive manner, including all villages, and the results should be shared with the producers, and the producers should be informed about the subject through agricultural publishing.

#### **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

#### **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

#### **Authorship Contribution Statement**

Concept: Buyukfiliz, F., Belliturk, K.; Design: Erkocak, A., Buyukfiliz, F., Data Collection or Processing: Buyukfiliz, F., Belliturk, K.; Literature Search: Buyukfiliz, F., Erkocak, A., Acikbas, B.; Writing, Review and Editing: Erkocak, A.; Buyukfiliz, F.

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**An Investigation on Organic Food Purchase Intention on E-Commerce Platforms**

E-Ticaret Platformlarında Organik Gıda Satın Alma Niyeti Üzerine Bir İnceleme

**Hasan Selçuk ETİ<sup>1\*</sup>****Abstract**

This study aimed to examine the effects of health consciousness, environmental consciousness, perceived trust, perceived value, and perceived risk on organic food purchase intention on e-commerce platforms. Additionally, it aimed to investigate the mediating role of attitude in these relationships. The research, designed in the relational screening model, was conducted with a total of 400 participants selected through convenience sampling among organic food consumers. The data collected through an online survey method were analyzed using SPSS v26 software. Validity and reliability analyses of the scales used in the research were conducted, the normality of data distribution was tested, and relationships between variables were examined using Pearson correlation analysis. Three-stage multivariate regression analyses were performed to examine the mediating effect. The research findings revealed that health consciousness, environmental consciousness, perceived trust, and perceived value had significant positive effects on both attitude and purchase intention, while perceived risk had significant negative effects on both variables. Additionally, attitude was found to have a significant positive effect on purchase intention. Mediation analyses demonstrated that attitude played a partial mediating role in the relationships between health consciousness and environmental consciousness with purchase intention, while it had a full mediating role in the relationships between perceived trust, perceived value, and perceived risk with purchase intention. In light of these findings, it is recommended that businesses selling organic food on e-commerce platforms should develop marketing strategies emphasizing consumers' health and environmental consciousness, and adopt attitude-focused approaches towards building trust, enhancing value perception, and reducing risk perception. Furthermore, it is advised that they should consider both rational and emotional aspects of consumer decision-making in website design and communication strategies, and develop specific strategies for first-time shoppers.

**Keywords:** Organic food, E-commerce, Consumer behavior, Purchase intention, Attitude

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## Öz

Bu araştırmada sağlık bilinci, çevre bilinci, algılanan güven, algılanan değer ve algılanan riskin, e-ticaret platformlarında organik gıda satın alma niyeti üzerindeki etkilerinin incelenmesi amaçlanmıştır. Bunun yanında, söz konusu ilişkilerde tutumun aracılık rolünün incelenmesi de hedeflenmiştir. İlişkisel tarama modelinde tasarlanan araştırma, organik gıda tüketicileri arasından kolayda örnekleme yöntemi ile seçilen toplam 400 katılımcıyla yürütülmüştür. Çevrimiçi anket yöntemiyle toplanan veriler, SPSS v26 yazılımı kullanılarak analiz edilmiştir. Araştırmada kullanılan ölçeklerin geçerlik ve güvenirlik analizleri yapılmış, verilerin normal dağılıma uygunluğu test edilmiş ve değişkenler arasındaki ilişkiler Pearson korelasyon analizi ile incelenmiştir. Aracılık etkisinin incelenmesinde ise üç aşamalı çok değişkenli regresyon analizleri gerçekleştirilmiştir. Araştırma sonucunda sağlık bilinci, çevre bilinci, algılanan güven ve algılanan değer hem tutum hem de satın alma niyeti üzerinde pozitif yönde anlamlı etkileri tespit edilirken, algılanan riskin her iki değişken üzerinde negatif yönde anlamlı etkileri belirlenmiştir. Ayrıca tutumun, satın alma niyeti üzerinde pozitif yönde anlamlı bir etkiye sahip olduğu görülmüştür. Aracılık analizleri sonucunda, tutumun sağlık bilinci ve çevre bilinci ile satın alma niyeti arasındaki ilişkilerde kısmi aracılık rolü üstlendiği; algılanan güven, algılanan değer ve algılanan risk ile satın alma niyeti arasındaki ilişkilerde ise tam aracılık rolü oynadığı tespit edilmiştir. Bu bulgular ışığında, e-ticaret platformlarında organik gıda satışı yapan işletmelere, tüketicilerin sağlık ve çevre bilincini vurgulayan pazarlama stratejileri geliştirmeleri, güven oluşturma, değer algısını artırma ve risk algısını azaltma yönünde tutum odaklı yaklaşımlar benimsemeleri önerilmektedir. Ayrıca, web sitesi tasarımı ve iletişim stratejilerinde tüketici karar verme sürecinin hem rasyonel hem de duygusal yönlerini dikkate almaları ve özellikle ilk kez alışveriş yapacak tüketicilere yönelik özel stratejiler geliştirmeleri tavsiye edilmektedir.

**Anahtar Kelimeler:** Organik gıda, E-ticaret, Tüketici davranışı, Satın alma niyeti, Tutum

## 1. Introduction

In today's food industry, organic products represent a category of foods produced without harmful industrial compounds and chemical additives that could potentially impact environmental and human wellbeing (Gür and Erdem, 2023). The fundamental characteristic of these products lies in their natural production methods, specifically avoiding synthetic substances including chemical fertilizers, pesticides, antibiotics, and genetically modified components (Gad Mohsen and Dacko, 2013). These products have established themselves in the marketplace as environmentally conscious options, cultivated through natural processes that exclude harmful synthetic substances (Bhardwaj et al., 2024). The regulatory framework established by the USDA specifically outlines organic certification requirements, prohibiting conventional pesticides, synthetic fertilizers, sewage sludge applications, and radiation treatments. Additionally, these standards extend to animal products, mandating the absence of routine antibiotic treatments and growth hormones, while ensuring no genetic modification occurs throughout the production chain (Morath, 2023). Studies suggest that consumers generally view organically produced foods as offering enhanced safety, health benefits, nutritional content, and flavor profiles compared to conventional alternatives (Eyinade et al., 2021). This positive perception has contributed to expanding market demand, fostering significant development in the organic food sector (Rana and Paul, 2017; Gür and Erdem, 2023). Industry analyses indicate sustained expansion in global organic markets, with positive growth trajectories anticipated for the future (Hamzaoui-Essoussi and Zahaf, 2012). This market evolution has captured widespread attention across various stakeholder groups. Consequently, understanding consumer behavior and motivations in organic food purchases has emerged as a crucial area of marketing research (Rahmawati et al., 2018; Kushwah et al., 2019; Pahari et al., 2023).

On the other hand, the digital revolution has fundamentally transformed consumer behavior patterns, with internet adoption rates showing remarkable growth and reshaping traditional purchasing habits (Şahin, 2020). Recent statistics from the Turkish Statistical Institute (TurkStat) demonstrate this transformation, revealing that internet penetration in Turkey reached 87.1% by 2023. The data further indicates that 49.5% of individuals engaged in online purchasing activities, with 37.1% specifically acquiring food products through digital channels (TurkStat, 2023). While traditional organic food distribution primarily relies on specialized stores and organic markets, the digital transformation has prompted many organic food retailers to establish online presence through e-commerce platforms (Liang, 2014; Wang and Somogyi, 2018). The transition to digital marketplaces has introduced new dynamics in organic food consumer behavior. Research has identified several key factors influencing online organic food purchasing decisions, encompassing various psychological and practical considerations. These determinants include consumers' health awareness, environmental consciousness, trust perceptions, value assessments, risk evaluations, and general attitudes toward organic products in the digital marketplace (Yin et al., 2010; Irianto, 2015; Hsu et al., 2016; Yadav and Pathak, 2016; Rahmawati et al., 2018; Nguyen et al., 2019; Pham et al., 2019; Kusno et al., 2022; Zayed et al., 2022; Pahari et al., 2023; Tao and Chao, 2024).

In this context, the present research aims to explore how multiple consumer-centric factors - specifically health consciousness, environmental consciousness, perceived trust, perceived value, and perceived risk - influence consumers' intentions to purchase organic food products through digital commerce channels. Furthermore, this study aims to elucidate the mediating role of attitudinal disposition in the relationship between these determinant factors and organic food purchase intentions in the e-commerce context.

## 2. Literature Review

Health consciousness is a concept that expresses individuals' awareness of their own health and their tendency to adopt a healthy lifestyle (Pahari et al., 2023). This concept is considered an important factor shaping consumers' food choices and dietary habits. Consumers with high health consciousness tend to gravitate towards foods that are high in nutritional value, free from additives, and produced by natural methods (Paul and Rana, 2012; Basha et al., 2015; Çakmakçı et al., 2024). In this context, organic foods stand out as an attractive option for health-conscious consumers. Research shows that health consciousness has a positive effect on organic food purchase intention (Yin et al., 2010; Hsu et al., 2016; Yadav and Pathak, 2016; Nguyen et al., 2019; Pahari et al., 2023).

Environmental consciousness represents an individual's ecological awareness and commitment, encompassing their sensitivity to environmental challenges and inclination towards eco-friendly product choices (Yadav and Pathak, 2016; Zayed et al., 2022). This mindset has emerged as a crucial determinant in shaping consumer purchasing decisions and serves as a cornerstone for sustainable consumption patterns (Joshi and Rahman, 2015; Çakmakçı et al., 2024).

Individuals exhibiting strong environmental consciousness demonstrate a marked preference for products that minimize ecological impact. The organic food sector aligns particularly well with these environmental values, offering production methodologies that present significantly reduced environmental impacts compared to traditional agricultural practices. Empirical studies consistently demonstrate a robust positive correlation between environmental consciousness and organic food purchasing intentions (Yin et al., 2010; Irianto, 2015; Yadav and Pathak, 2016; Nguyen et al., 2019; Pham et al., 2019; Zayed et al., 2022; Pahari et al., 2023).

Perceived trust stands within the digital marketplace as a fundamental psychological component that shapes consumers' evaluation of online platform credibility and authenticity (Kim and Peterson, 2017). This multifaceted construct encompasses several key elements, including data security protocols, product authenticity assurance, and fulfillment reliability (Ling et al., 2011). The absence of trust creates an insurmountable barrier to e-commerce engagement, effectively preventing meaningful transaction relationships from developing (Avcı, 2024). This trust factor becomes particularly crucial in the context of specialty products like organic foods, where quality assurance holds paramount importance. Empirical investigations have consistently demonstrated that trust perceptions regarding e-commerce platforms significantly influence consumers' willingness to purchase organic products through digital channels (Sukrat et al., 2015; Sohn et al., 2020).

Perceived value encompasses a complex evaluation framework where consumers weigh product or service benefits against acquisition costs. This assessment incorporates multiple value dimensions, spanning functional utility, emotional satisfaction, social impact, and knowledge enhancement (Kushwah et al., 2019). When applied to organic food products, this value perception represents consumers' comprehensive assessment balancing health benefits, environmental sustainability, and societal impact against premium pricing considerations. Empirical evidence consistently demonstrates that these value perceptions play a significant role in driving organic food purchase intentions (Konuk, 2018; Kushwah et al., 2019; Pahari et al., 2023).

Perceived risk encompasses consumers' subjective assessment of uncertainties and potential adverse outcomes associated with product or service acquisition. In digital commerce environments, this risk perception takes on multiple dimensions, reflecting consumers' evaluation of possible negative consequences inherent in online transactions (Varghese et al., 2022). The absence of physical interaction in digital marketplaces introduces additional risk elements beyond traditional retail channels, potentially influencing consumer decision-making patterns (Li, 2013; Yılmaz, 2018). Studies examining online organic food purchasing behavior have identified an inverse relationship between perceived risk and purchase intention, suggesting that heightened risk perception acts as a deterrent to organic food acquisition through digital platforms (Rahmawati et al., 2018; Kushwah et al., 2019).

Attitude represents an individual's evaluative predisposition, manifesting as positive or negative assessments toward specific objects, behaviors, or concepts (Ajzen, 1991). In the context of online organic food purchasing, these attitudinal orientations reflect consumers' overall evaluation of digital platforms as a medium for organic food acquisition (Şahin, 2020). This multifaceted construct integrates cognitive elements (including utility perceptions and usability assessments), affective components (encompassing trust and satisfaction), and behavioral aspects (drawing from previous experiences) (Ajzen, 1991; Davis, 1989). Extensive empirical research has consistently demonstrated a robust positive correlation between attitudinal dispositions and organic food purchase intentions in digital environments (Irianto, 2015; Teng and Wang, 2015; Hsu et al., 2016; Yadav and Pathak, 2016; Rahmawati et al., 2018; Zayed et al., 2022; Pahari et al., 2023).

### **3. Materials and Methods**

This study was prepared under the permission numbered T2024-2170, dated 07/10/2024, from the Ethics Committee of Tekirdag Namik Kemal University Social Sciences and Humanities Scientific Research and Publication.

#### **3.1. Research Model**

The methodological framework of this research employs quantitative analytical techniques to explore consumer behavior patterns regarding organic food acquisition through digital platforms. Following a correlational research design, this research investigates the strength and nature of relationships among multiple variables (Karasar, 2022). The analytical framework incorporates five predictor variables: health consciousness, environmental consciousness, perceived trust, perceived value, and perceived risk, with purchase intention serving as the outcome variable.

Additionally, the research examines consumer attitude as a mediating variable in these relationships. The conceptual framework illustrating these relationships is depicted in *Figure 1*.

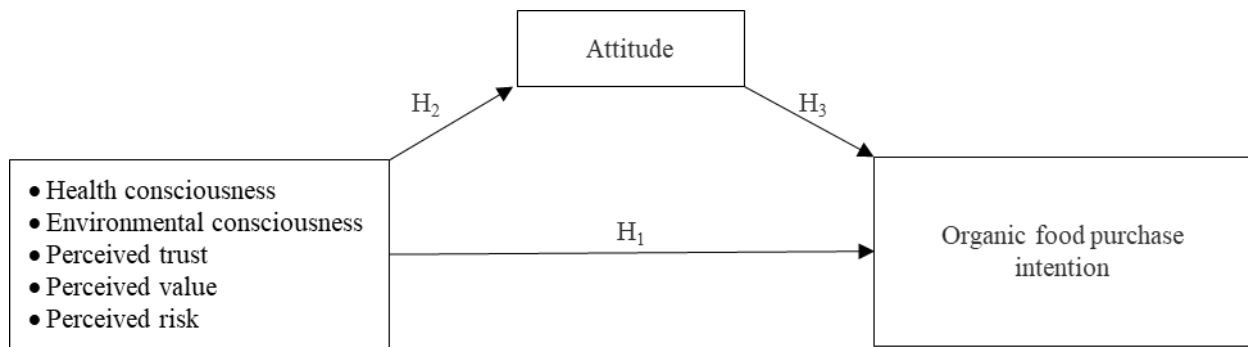


**Figure 1. Research model**

Based on the theoretical framework and literature review discussed above, the following hypotheses were developed:

H<sub>1</sub>: Health consciousness, environmental consciousness, perceived trust, perceived value, and perceived risk have significant effects on purchase intention for organic food on e-commerce platforms.

H<sub>2</sub>: Health consciousness, environmental consciousness, perceived trust, perceived value, and perceived risk have significant effects on attitude toward purchasing organic food on e-commerce platforms.

H<sub>3</sub>: Attitude has a positive effect on purchase intention for organic food on e-commerce platforms.

H<sub>4</sub>: Attitude mediates the relationship between independent variables (health consciousness, environmental consciousness, perceived trust, perceived value, perceived risk) and purchase intention for organic food on e-commerce platforms.

### 3.2. Sample

The study population encompasses Turkish residents aged 18 and above who have engaged in organic food purchases through digital platforms within the previous twelve months. The sampling methodology employed a non-probabilistic convenience sampling approach, which facilitates participant recruitment based on accessibility and willingness to participate (Etikan et al., 2016). This sampling strategy was selected for its practical advantages in terms of resource efficiency and time management.

Recent statistical data from TurkStat (2023) indicates that internet penetration in Turkey has reached 87.1% of the population. Within this digital landscape, 49.5% of individuals engage in online purchasing activities, with 37.1% specifically acquiring food products through digital channels. These figures suggest an approximate potential population of 13.5 million individuals who utilize e-commerce platforms for organic food purchases, though precise figures for this specific consumer segment remain unavailable.

Following the statistical guidelines proposed by Yazıcıoğlu and Erdoğan (2014), a sample size of 384 participants is deemed sufficient for populations exceeding one million, assuming a 95% confidence level and 5% margin of error. The current study successfully recruited 400 participants, exceeding the minimum threshold for statistical validity. All study participants received comprehensive information regarding the research objectives and data confidentiality protocols, and provided voluntary consent for participation.

### 3.3. Measures

Data collection was implemented through digital survey methodology, with questionnaire distribution occurring via various online channels including social networking platforms, electronic mail, and messaging applications. The demographic questions in the questionnaire form were prepared by the researcher. The research utilized several validated measurement scales. Health Consciousness Scale contains 5 items ( $\alpha=0.865$ ) measuring participants' health awareness and concerns (Gül and Erdem, 2023). Environmental Consciousness Scale contains 4 items ( $\alpha=0.804$ ) measuring environmental awareness and concerns (Gül and Erdem, 2023). Perceived Trust Scale contains 3 items ( $\alpha=0.868$ ) measuring participants' trust in e-commerce platforms (Avcı, 2004). Perceived Value Scale contains 3 items ( $\alpha=0.747$ ) measuring value perceptions of organic food purchases through e-commerce (Avcı, 2004). Perceived Risk



Scale contains 3 items ( $\alpha=0.780$ ) measuring risk perceptions related to online organic food shopping (Yılmaz, 2018). Attitude Scale contains 4 items ( $\alpha=0.941$ ) measuring attitudes toward purchasing organic food through e-commerce platforms (Şahin, 2020). Purchase Intention Scale contains 4 items ( $\alpha=0.925$ ) measuring intentions to purchase organic food through e-commerce platforms (Şahin, 2020). All scales employed five-point Likert-type response formats, ranging from strong disagreement (1) to strong agreement (5).

### 3.4. Procedure

Statistical analyses were performed utilizing SPSS v26 statistical software package. Frequency analysis was used to analyze the distribution of participants according to their demographic characteristics. Exploratory factor analysis was conducted to examine the validity of the scales used in the study. In addition, Cronbach alpha coefficients were calculated to examine the reliability of the scales. To evaluate the normality distribution characteristics of the dataset, distribution parameters were examined through skewness and kurtosis metrics. Pearson correlation analysis was conducted to examine the interrelationships among study variables. Finally, this study employed the mediation analysis framework developed by Baron and Kenny (1986) to examine how health consciousness, environmental consciousness, perceived trust, perceived value, and perceived risk influence organic food purchase intentions in e-commerce contexts, with particular attention to attitude's mediating function. The analytical procedure follows a three-stage regression sequence. The initial stage evaluates the independent variable's impact on the proposed mediator. The second stage assesses the direct relationship between the independent and dependent variables. The final stage examines the concurrent effects of both independent and mediating variables on the outcome variable. For establishing mediation, three essential criteria must be satisfied:

- The independent variable should demonstrate a significant effect on the mediator in the first regression equation
- The independent variable should significantly influence the dependent variable in the second equation
- The mediator should maintain significant influence on the dependent variable when both predictors are simultaneously considered

When these conditions are met, the independent variable's effect magnitude in the third equation should be diminished compared to its second-equation effect. Baron and Kenny (1986) distinguish between two mediation types: partial mediation, where the independent variable retains a reduced but significant effect, and complete mediation, where the independent variable's effect becomes non-significant in the presence of the mediator.

## 4. Results

### 4.1. Demographic Statistics of the Participants

A total of 400 people who had purchased organic food through digital platforms in the last twelve months participated in the research. The demographic composition of the participants is detailed in *Table 1*.

**Table 1. Demographic statistics of the participants**

| Variable  | Category              | f   | %    | Variable                        | Category                | f   | %    |
|-----------|-----------------------|-----|------|---------------------------------|-------------------------|-----|------|
| Gender    | Female                | 212 | 53.0 | Marital Status                  | Single                  | 138 | 34.5 |
|           | Male                  | 188 | 47.0 |                                 | Married                 | 262 | 65.5 |
| Age       | 20-29                 | 88  | 22.0 | Occupation                      | Private sector employee | 142 | 35.5 |
|           | 30-39                 | 183 | 45.8 |                                 | Public sector employee  | 123 | 30.8 |
|           | 40-49                 | 73  | 18.3 |                                 | Self-employed           | 57  | 14.2 |
|           | 50 and above          | 56  | 14.0 |                                 | Student                 | 34  | 8.5  |
| Education | High school and below | 82  | 20.5 |                                 | Retired                 | 22  | 5.5  |
|           | University            | 202 | 50.5 |                                 | Unemployed              | 22  | 5.5  |
|           | Graduate              | 116 | 29.0 | Annual                          | 1-10 times              | 224 | 56.0 |
| Income    | Below 50.000 TL       | 103 | 25.8 | Organic Food Purchase Frequency | 11-20 times             | 114 | 28.5 |
|           | 50.000-100.000 TL     | 180 | 45.0 |                                 | 21-30 times             | 48  | 12.0 |
|           | Over 100.000 TL       | 117 | 29.3 |                                 | Over 30 times           | 14  | 3.5  |

Source: Author calculation.

As seen in *Table 1*, the majority of participants were female (53.0%, n = 212) and married (65.5%, n = 262). The age distribution showed that nearly half of the participants were between 30-39 years old (45.8%, n = 183), followed by those aged 20-29 (22.0%, n = 88). Regarding education level, half of the participants had a university degree (50.5%, n = 202), while 29.0% (n = 116) held graduate degrees. In terms of occupation, private sector employees constituted the largest group (35.5%, n = 142), followed by public sector employees (30.8%, n = 123). Most participants had moderate income level (45.0%, n = 180). The majority of participants purchased organic food 1-10 times annually through e-commerce platforms (56.0%, n = 224), while a small portion made more than 30 purchases per year (3.5%, n = 14).

#### 4.2. Validity and Reliability Analysis

Exploratory factor analysis was conducted to examine the validity of the scales used in the study. In addition, Cronbach alpha coefficients were calculated to examine the reliability of the scales. The results of the analysis are presented in *Table 2*.

**Table 2. Validity and Reliability Analysis Results**

| Scale                                                           | Item  | Factor Loadings |      |      |      |      |      |      | Variance Explained | Cronbach Alpha |
|-----------------------------------------------------------------|-------|-----------------|------|------|------|------|------|------|--------------------|----------------|
|                                                                 |       | (1)             | (2)  | (3)  | (4)  | (5)  | (6)  | (7)  |                    |                |
| Health consciousness                                            | Item1 | .750            |      |      |      |      |      |      | 12.824             | .865           |
|                                                                 | Item2 | .704            |      |      |      |      |      |      |                    |                |
|                                                                 | Item3 | .765            |      |      |      |      |      |      |                    |                |
|                                                                 | Item4 | .781            |      |      |      |      |      |      |                    |                |
|                                                                 | Item5 | .767            |      |      |      |      |      |      |                    |                |
| Environmental consciousness                                     | Item1 |                 |      |      | .669 |      |      |      | 9.982              | .811           |
|                                                                 | Item2 |                 |      |      | .812 |      |      |      |                    |                |
|                                                                 | Item3 |                 |      |      | .817 |      |      |      |                    |                |
|                                                                 | Item4 |                 |      |      | .814 |      |      |      |                    |                |
| Perceived trust                                                 | Item1 |                 |      |      |      |      | .910 |      | 8.987              | .842           |
|                                                                 | Item2 |                 |      |      |      |      | .892 |      |                    |                |
|                                                                 | Item3 |                 |      |      |      |      | .590 |      |                    |                |
| Perceived value                                                 | Item1 |                 |      |      |      | .830 |      |      | 9.387              | .869           |
|                                                                 | Item2 |                 |      |      |      | .838 |      |      |                    |                |
|                                                                 | Item3 |                 |      |      |      | .887 |      |      |                    |                |
| Perceived risk                                                  | Item1 |                 |      |      |      |      |      | .760 | 7.608              | .815           |
|                                                                 | Item2 |                 |      |      |      |      |      | .704 |                    |                |
|                                                                 | Item3 |                 |      |      |      |      |      | .776 |                    |                |
| Attitude                                                        | Item1 |                 |      | .756 |      |      |      |      | 11.401             | .871           |
|                                                                 | Item2 |                 |      | .825 |      |      |      |      |                    |                |
|                                                                 | Item3 |                 |      | .825 |      |      |      |      |                    |                |
|                                                                 | Item4 |                 |      | .729 |      |      |      |      |                    |                |
| Purchase intention                                              | Item1 |                 | .927 |      |      |      |      |      | 11.606             | .871           |
|                                                                 | Item2 |                 | .711 |      |      |      |      |      |                    |                |
|                                                                 | Item3 |                 | .745 |      |      |      |      |      |                    |                |
|                                                                 | Item4 |                 | .812 |      |      |      |      |      |                    |                |
| KMO = .830, Barlett's Test: $\chi^2(325) = 6065.806$ , p = .000 |       |                 |      |      |      |      |      |      |                    |                |
| Total Variance Explained = 71.795                               |       |                 |      |      |      |      |      |      |                    |                |

Source: Author calculation.

It is indicated that for factor analysis to be conducted, the Kaiser-Meyer-Olkin (KMO) coefficient should exceed the threshold value of 0.5, and Bartlett's test of sphericity should yield significant results (Kline, 2008). Statistical assessment revealed favorable conditions for factor analysis, with the KMO coefficient exceeding the threshold value of 0.5 (KMO = .830), and Bartlett's sphericity test yielding significant results ( $\chi^2(325) = 6065.806$ , p = .000), meeting established criteria. The analysis identified a seven-factor solution, with all items demonstrating robust factor loadings surpassing 0.50, collectively accounting for 71.795% of the total variance. Internal consistency reliability was

demonstrated through Cronbach's Alpha coefficients, with all subscales exceeding 0.80, indicating strong measurement reliability (Kline, 2008). Within this framework, it was concluded that the scale used in the research was both a valid and reliable measurement tool.

#### 4.3. Normality Analysis

To evaluate the normality distribution characteristics of the dataset, distribution parameters were examined through skewness and kurtosis metrics. Analysis results are presented in *Table 3*.

**Table 3. Normality analysis results**

| Variable                    | Skewness | Kurtosis |
|-----------------------------|----------|----------|
| Health consciousness        | -.413    | -.079    |
| Environmental consciousness | -.289    | -.675    |
| Perceived trust             | -.877    | .222     |
| Perceived value             | .132     | -.796    |
| Perceived risk              | .597     | -.148    |
| Attitude                    | -.863    | .232     |
| Purchase intention          | -.362    | -.244    |

Source: Author calculation.

The analysis revealed that skewness and kurtosis indicators fell within the acceptable range of -3 to +3 for all study variables, satisfying established criteria for normal distribution (Kline, 2008). This confirmation of normality provided justification for the subsequent application of parametric statistical procedures in the analysis framework.

#### 4.4. Correlation Analysis

Pearson correlation analysis was conducted to examine the interrelationships among study variables. Analysis results are presented in *Table 4*.

**Table 4. Pearson correlation analysis results**

| Variable                        | (1)     | (2)    | (3)     | (4)     | (5)     | (6)    | (7) |
|---------------------------------|---------|--------|---------|---------|---------|--------|-----|
| (1) Health consciousness        | 1       |        |         |         |         |        |     |
| (2) Environmental consciousness | .314**  | 1      |         |         |         |        |     |
| (3) Perceived trust             | .411**  | .191** | 1       |         |         |        |     |
| (4) Perceived value             | .346**  | .190** | .233**  | 1       |         |        |     |
| (5) Perceived risk              | -.322** | -.094* | -.452** | -.262** | 1       |        |     |
| (6) Attitude                    | .426**  | .249** | .364**  | .348**  | -.371** | 1      |     |
| (7) Purchase intention          | .445**  | .264** | .347**  | .278**  | -.312** | .473** | 1   |

\*  $p < .05$ , \*\*  $p < .01$

Source: Author calculation.

The analytical results demonstrate a consistent pattern wherein perceived risk exhibits negative associations with all other constructs, while the remaining variables show positive intercorrelations. Statistical significance ( $p < .05$ ) was observed across all variable relationships. These correlation patterns confirm the presence of linear relationships among the variables, thereby satisfying a fundamental requirement for subsequent parametric statistical analyses.

#### 4.5. Mediation Analysis

The study aimed to examine the effects of health consciousness, environmental consciousness, perceived trust, perceived value and perceived risk on organic food purchase intention on e-commerce platforms and the mediating role of attitude in these relationships. In this regard, three-step multivariate regression analyses were conducted by following the mediation analysis process proposed by Baron and Kenny (1986). *Table 5* presents the combined analysis results.

The mediation analysis proceeded through three distinct phases. The initial phase examined how the independent variables influenced the mediator (attitude). The findings revealed significant effects from health consciousness ( $\beta = .220$ ,  $p < .01$ ), environmental consciousness ( $\beta = .105$ ,  $p < .05$ ), perceived trust ( $\beta = .129$ ,  $p < .01$ ), perceived value

( $\beta = .173, p < .01$ ), and perceived risk ( $\beta = -.187, p < .01$ ). This model demonstrated statistical significance ( $F = 33.183, p < .01$ ), accounting for 28.7% of the variance ( $R^2 = .287$ ).

**Table 5. Mediation analysis results**

| Independent Variables       | Step 1<br>DV = Attitude             |        | Step 2<br>DV = Purchase Intention   |        | Step 3<br>DV = Purchase Intention   |        |
|-----------------------------|-------------------------------------|--------|-------------------------------------|--------|-------------------------------------|--------|
|                             | $\beta$                             | p      | $\beta$                             | p      | $\beta$                             | p      |
| Health consciousness        | .220                                | .000** | .280                                | .000** | .219                                | .000** |
| Environmental consciousness | .105                                | .020*  | .122                                | .008** | .093                                | .038*  |
| Perceived trust             | .129                                | .009** | .130                                | .012*  | .094                                | .060   |
| Perceived value             | .173                                | .000** | .094                                | .046*  | .045                                | .323   |
| Perceived risk              | -.187                               | .000** | -.128                               | .010*  | -.075                               | .122   |
| Attitude                    | -                                   | -      | -                                   | -      | .279                                | .000** |
| Model                       | F = 33.183<br>R <sup>2</sup> = .287 |        | F = 28.812<br>R <sup>2</sup> = .258 |        | F = 31.202<br>R <sup>2</sup> = .312 |        |

\*  $p < .05$ , \*\*  $p < .01$   
Source: Author calculation.

The second phase investigated the direct relationships between independent variables and purchase intention. The analysis uncovered significant influences from health consciousness ( $\beta = .280, p < .01$ ), environmental consciousness ( $\beta = .122, p < .01$ ), perceived trust ( $\beta = .130, p < .05$ ), perceived value ( $\beta = .094, p < .05$ ), and perceived risk ( $\beta = -.128, p < .05$ ). This model achieved significance ( $F = 28.812, p < .01$ ), explaining 25.8% of the variance ( $R^2 = .258$ ).

The concluding phase assessed the simultaneous effects of both independent variables and attitude on purchase intention. Upon incorporating attitude ( $\beta = .279, p < .01$ ), the analysis revealed distinctive patterns: health consciousness ( $\beta = .219, p < .01$ ) and environmental consciousness ( $\beta = .093, p < .05$ ) maintained significance despite reduced effects, while perceived trust ( $\beta = .094, p > .05$ ), perceived value ( $\beta = .045, p > .05$ ), and perceived risk ( $\beta = -.075, p > .05$ ) lost their significant direct effects. This final model demonstrated enhanced explanatory power ( $F = 31.202, p < .01$ ;  $R^2 = .312$ ).

These results indicate that attitude serves as a partial mediator in the relationships linking health and environmental consciousness to purchase intention, while functioning as a full mediator for the effects of perceived trust, value, and risk on purchase intention. According to the results, all hypotheses of the study were supported.

## 5. Discussion

The study aimed to examine the effects of health consciousness, environmental consciousness, perceived trust, perceived value and perceived risk on organic food purchase intention on e-commerce platforms and the mediating role of attitude in these relationships. The research findings revealed that health consciousness and environmental consciousness had both direct and indirect effects through attitude (partial mediation) on purchase intention, while the effects of perceived trust, perceived value, and perceived risk on purchase intention were explained through attitude (full mediation).

A key observation from this study is the persistence of both health and environmental consciousness effects on purchase intention, even when accounting for attitudinal mediation. This dual influence pathway suggests these factors shape consumer behavior through both direct and indirect mechanisms. Such findings extend the current understanding of consumer decision-making in organic food purchases, aligning with multiple research outcomes across various cultural settings (Yin et al., 2010; Irianto, 2015; Hsu et al., 2016; Yadav and Pathak, 2016; Nguyen et al., 2019; Pham et al., 2019; Zayed et al., 2022; Pahari et al., 2023). For instance, environmental consciousness was found to directly impact green purchase intentions by Yadav and Pathak (2016), while Nguyen et al. (2019) documented direct health consciousness effects on organic food consumption patterns.

This study also revealed that attitude completely mediates the relationship between purchase intention and three key factors: perceived trust, value, and risk in e-commerce contexts. This suggests these elements primarily influence purchasing decisions by first shaping consumer attitudes toward organic food products on digital platforms. These

observations complement existing research findings (Konuk, 2018; Kushwah et al., 2019; Sohn et al., 2020). As demonstrated by Konuk (2018), attitude mediates perceived value's impact on organic food purchase intentions, while Sohn et al. (2020) established attitude's mediating role in trust-related purchase decisions on e-commerce platforms.

The complex interplay of factors influencing organic food purchase intentions in e-commerce, particularly the significant mediating function of attitude, strongly validates the theoretical framework proposed by the Theory of Planned Behavior (Ajzen, 1991). The theory's central premise regarding attitude's role in behavioral intention formation is well-supported by findings of this study, especially within the specific context of online organic food consumption. This validation enhances our understanding of consumer behavior in digital marketplaces while reinforcing the theory's explanatory capabilities.

## 6. Conclusion

This research investigated how various factors influence consumers' intention to purchase organic food through e-commerce platforms, with a particular focus on the mediating function of attitude. The investigation yielded several significant insights with both theoretical and practical relevance.

The analysis revealed a distinctive pattern regarding health and environmental consciousness, demonstrating their influence through both direct and indirect pathways via attitudinal mediation. This dual-path influence underscores how deeply these considerations are embedded in consumer decision-making processes for organic food purchases. The persistence of direct effects, even when accounting for attitudinal factors, emphasizes the fundamental importance of these awareness factors in driving purchase decisions.

The findings also demonstrated that attitude fully mediates the relationship between purchase intention and three key e-commerce factors: perceived trust, value, and risk. This suggests that these elements primarily shape purchasing decisions by first influencing consumer attitudes, rather than directly affecting behavioral intentions. Such insights highlight the crucial role of attitude formation in digital marketplace dynamics.

Finally, demographic findings indicate that the research sample predominantly consists of individuals with high education levels, middle age group, and moderate-income level. This profile is significant as it reflects the general characteristics of consumers who purchase organic food through e-commerce platforms in Turkey. However, the fact that the vast majority of participants only purchase organic food 1-10 times per year (56.0%) suggests that this channel has not yet been widely adopted as a common shopping method.

From a practical perspective, these findings offer several implications for e-commerce platforms and organic food retailers:

- Marketing strategies should emphasize both environmental and health benefits of organic foods, as these factors have direct influences on purchase intention.
- E-commerce platforms should focus on building trust, enhancing value perception, and reducing perceived risk through measures that positively influence consumer attitudes.
- Website design and communication strategies should address both rational and emotional aspects of consumer decision-making, given the significant mediating role of attitudes.
- Special attention should be paid to first-time buyers, as the majority of participants (56.0%) only purchased organic food 1-10 times annually through e-commerce platforms.

Several limitations should be noted when interpreting the research outcomes. The geographical scope, being limited to Turkey, may restrict the broader applicability of these findings across different cultural settings. Furthermore, the reliance on convenience sampling techniques potentially affects the sample's representativeness of the wider population. To address these methodological constraints, future studies should implement probability-based sampling approaches and explore cross-cultural comparative analyses to validate the conclusions across diverse contexts. Notwithstanding these methodological boundaries, this investigation advances the current understanding of e-commerce organic food consumption patterns by illuminating the intricate interplay between multiple factors affecting purchase intentions, with particular emphasis on attitude's pivotal mediating function in these relationships.

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### **Ethical Statement**

This study was prepared under the permission numbered T2024-2170, dated 07/10/2024 from the Ethics Committee of Tekirdag Namik Kemal University Social Sciences and Humanities Scientific Research and Publication.

### **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

### **Authorship Contribution Statement**

The contribution is made by the only one author.



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## Metropol Çeperinde Organik Tarım ve Devamlılığını Etkileyen Faktörler: Bursa Örneği

### Organic Farming on the Urban Fringe and the Factors Affecting Its Continuity: The Case of Bursa

Ebru SEÇKİN<sup>1</sup>, Senem KOZAMAN AYGÜN<sup>2\*</sup>

#### Öz

Son yıllarda kent nüfusunun artması, tarım alanlarının yapılaşmaya açılması, kırsal alanlarda yaşayanların kente göç etmesi gıda güvenliğiyle ilgili endişeleri beraberinde getirmiştir. Bu noktada tarım topraklarının sürdürülebilirliği ve yerel gıda sistemleri kentsel politikaların gündeminde yer almaya başlamıştır. Özellikle üretimin kısıtlı olduğu büyük şehirlerde, sağlıklı gıdaya erişim başat konulardan biri haline gelmiş, yerel yönetimler bu konularda çözüm arayışlarına girmiştir. Bu bağlamda, makalede büyük şehirlerin çeperinde organik tarım faaliyetlerinin gelişimi, kentsel nüfusun yoğun olduğu Bursa Metropolü üzerinden ele alınmıştır. Çalışma kapsamında Bursa’da organik üretimin mekânsal özellikleri tespit edilmiş, üreticilerle anket çalışması yapılarak organik tarımın devamlılığını etkileyen üretici ve üretime dair mikro ölçekli yapısal faktörler karar ağacı modeliyle belirlenmiştir. Sonuç olarak, Bursa’da organik üretimin dağınık, küçük ölçekli olduğu ve Uludağ yakın çevresinde bulunan kırsal yerleşmelerde yoğunlaştığı görülmektedir. İlde organik üretime devam etme eğilimini en çok etkileyen faktörün yaş olduğu tespit edilmiştir. Organik üretim yapısına bakıldığında, geleneksel tarım geçmişine sahip deneyimli köylü çiftçilerin alıcı firmanın talebiyle faaliyeti gerçekleştirdiği izlenmektedir. Bu ilişki modeli küçük üreticilerin organik tarımı sürdürmelerinde olumlu gibi görünmekle beraber, gelirlerinde ve becerilerinde büyük bir değişiklik yaratmamaktadır. Diğer taraftan alıcı bağımlı bir ilişki ortaya çıkmakta, çiftçi tek başına kaldığında organik tarımın gereklerini yerine getirememektedir. Sonuçta bu üreticiler organik üretimden konvansiyonel üretime geri dönebilmektedir. Bursa’da tarladan tüketiciye kadar olan sürecin kontrolünü elinde bulunduran az sayıda organik üretici bulunmaktadır. Bunların sektördeki dayanıklılığı ve organik tarıma devam etme eğilimleri sözleşmeli üreticilere göre daha yüksektir. Dolayısıyla küçük ölçekli işletmelerin yoğunlaştığı bölgede kısıtlı sosyal ve finansal kaynakların yarattığı kırılganlığı gidermek ve organik tarımı genç üreticilerin dahil olduğu toplumsal bir pratik haline dönüştürmek için beşeri ve sosyal sermayenin güçlendirilmesi gerektiği, tarımsal desteklerin değerli olduğu anlaşılmaktadır.

**Anahtar Kelimeler:** Organik tarım, Yerel gıda sistemi, Bursa, Türkiye

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## Abstract

In recent years, the rapid expansion of urban areas and the concomitant reduction in agricultural land have raised concerns about food security. Access to healthy food has emerged as a significant concern, particularly in metropolitan areas where locally produced food is limited. The sustainability of agricultural land in the urban fringe and the search for solutions to improve local food systems are prominent issues on the agendas of many countries. In this context, the objective of the article is to gain insight into the development of organic farming activities in the periphery of metropolitan cities, in the case of Bursa. The study's objective was to ascertain the spatial characteristics of organic production in Bursa. Furthermore, a survey was conducted with organic producers to ascertain the micro-scaled factors influencing the continuity of organic agriculture, employing the decision tree model. Consequently, the organic production in Bursa is dispersed, characterized by small-scale enterprises, and concentrated in rural settlements around Uludağ. The analysis indicates that the primary factor influencing the continuation of organic production in the province is the age of the producers. An examination of the structure of organic production reveals that peasant farmers conduct organic production with a traditional agricultural background at the request of the buyer company. While this relationship model appears beneficial for small producers in maintaining organic agriculture, it does not result in a change in income or skills for small producers. Instead, it creates a dependency on the buyer, and farmers cannot fulfill the requirements of organic agriculture without external support. As a result, these producers may revert to conventional production from organic production. In Bursa, a limited number of large-scale organic producers control the entire production process. These producers demonstrate greater resilience in the sector and a stronger inclination to continue organic farming than their contracted counterparts. Consequently, it is evident that human and social capital must be reinforced and that agricultural subsidies are invaluable in mitigating the vulnerability resulting from the scarcity of social and financial resources in the region where small-scale enterprises are concentrated. Furthermore, it is essential to transform organic agriculture into a social practice involving young producers.

**Keywords:** Organic farming, Local food systems, Bursa, Türkiye

## 1. Giriş

Değişen ekolojik koşullar ve bu koşulları yüksek oranda olumsuz etkileyen antropojenik etmenler dikkate alındığında, mevcut kaynakların korunması ve sürdürülebilirliğinin sağlanması gerekliliği önem kazanmaktadır. Bu kaynaklardan tarım alanlarının sürdürülebilirliği sosyo-ekonomik ve çevresel açıdan gündem konularından biri haline dönüşmüştür. Tarımın olumsuz çevresel etkilerini azaltmak, toprak verimliliğini korumak, biyo-çeşitliliği desteklemek ve sektörün devamlılığını sağlamak amacıyla yenilikçi pratiklerin gelişiminde organik tarım üretim yöntemini tarımın geleceği olarak gören ülke politikalarında artış yaşanmaktadır (Çetin ve ark., 2020; UNDP, 2023). Ek olarak; iklim değişikliği, nüfus artışı ve kentleşmenin tarım alanları üzerinde yarattığı baskı üretim için gerekli olan arazi miktarını olumsuz etkilemektedir. Birleşmiş Milletler Gıda ve Tarım Örgütü (FAO) istatistiklerine göre, 2000-2020 yılları arasında dünyada 134 milyon hektarlık tarım alanı (yaklaşık Peru büyüklüğünde), 99 milyon hektar orman alanı (Mısır büyüklüğünde) kaybı yaşanmıştır (FAO, 2022a). Ayrıca kentlerde gıda güvenliğinin sağlanması için, küresel gıda zincirleri yerine kısa tedarik zincirlerinin önemine atıfla metropol çeperinde yer alan tarım alanlarının korunması ve sürdürülebilir tarım pratiklerinin gelişmesi gerektiği vurgulanmaktadır (Yacamán Ochoa ve ark. 2020).

Tarım ürünleri ticareti ve ihracata dayalı gıda tüketiminin gelecekte yaratabileceği bağımlılıklardan kurtulmak adına birçok ülke, devlet fonlarında tarıma daha çok pay ayırmaya başlamıştır. OECD ve FAO, 2023-2032 tüketim ve ticaret eğilimlerine dair ortaya koyduğu rakamlarda 10 yıl içinde toplam gıda tüketiminin %1.3 oranında artış göstereceğini belirtmektedir. Bu artış, tarımın iklim değişimi üzerindeki etkisine de yansımaktır. 10 yıl içerisinde tarım etken sera gazı emisyonunun %7.5 oranında yükseleceği öngörülmektedir (FAO, 2023). Bu bağlamda yine aynı uluslararası kuruluşlar, sürdürülebilir tarım uygulamalarının teşvik edilmesinin, iklim değişikliği ile mücadele ve gıda güvenliğinin sağlanması için stratejik öneme sahip olduğunu dile getirmektedir. Dünya genelinde, tarımda konvansiyonel yöntemlerin yaratmış olduğu toprak kirliliği, biyoçeşitliliğin azalması ve gıda sağlığı alanındaki endişeleri gidermek amacıyla, organik tarım uygulamaları modern tarımdaki bu krize uygun bir çözüm olarak görülmektedir (Aghasafari ve ark., 2020). FAO istatistiklerine göre dünyada 187 ülkede 72.3 milyon hektarda en az 3.1 milyon çiftçi organik tarım faaliyetleri içinde yer almaktadır (FAO, 2022a). 2009-2019 yılları arasında dünyada organik tarım yapılan alan büyüklüğü %102.4 oranında, üretici sayısı da %100.4 artış göstermiştir (TAGEM,2021).

Kent çeperi ve yakın çevresinde sürdürülebilir üretim metotlarından biri olan organik tarımın mevcut durumunu ortaya koymak ve yerel gıda sistemleri içine dâhil etmek gelişimini yönlendirmek adına önemlidir (Zasada ve ark., 2017; Yacamán Ochoa ve ark., 2020). Dünya tarım ihracatında önemli bir yere sahip olan Türkiye’de (2022 yılı Dünya Ticaret Merkezi istatistiklerine göre 23. sırada) organik tarımsal üretimin gelişim sürecini dış piyasa koşullarının şekillendirdiği görülmekle birlikte (Kenanoğlu Bektaş ve Miran, 2006), ülke içi talep de artmaktadır. Tarım ve Orman Bakanlığı verilerine göre Türkiye’de organik tarım, tarımsal üretimin ancak %1’ini oluşturmaktadır. Fakat üretim alanı büyüklüğü 2002 yılında doğal toplama alanı dâhil olmak üzere yaklaşık 90 bin hektardan, 2021 yılında 3,9 kat artarak yaklaşık 352 bin hektara ulaşmıştır. Toplam organik bitkisel üretim yapan çiftçi sayısı ise 2002 yılında yaklaşık 12 binden (geçiş süreci dâhil) 2021 itibarıyla 4 kat artarak yaklaşık 48 bin üreticiye yükselmiştir. Bu yükselişlere rağmen, süreç içindeki değişime bakıldığında hem çiftçi sayısı hem de üretim alanı büyüklüğünün 2014 yılında zirveye çıkıp daha sonraki yıllarda düşüşe geçtiği izlenmektedir (Tarım ve Orman Bakanlığı, 2023). Türkiye’de sürdürülebilir tarıma yönelme gerekliliği konvansiyonel tarımda kimyasal ilaç kullanımında dünya ortalamasının üzerinde değerlere sahip olunması nedeniyle daha önemli hale gelmektedir. FAO’nun 2020 yılı verilerine göre dünya ortalamasında tarım alanı başına (hektar) 1.81 kg. pestisit kullanımı gerçekleşiyorken, Türkiye’de bu değer 2.32’dir (FAO, 2022b). Diğer taraftan, dünya geneline benzer şekilde tarımsal alanlar gün geçtikçe yapay alanların baskısı altında yok olmaktadır. Toprak kaybı ve kirlenmesinin önüne geçmek ve kentleşme baskısını azaltmak adına, kent yakın çevresinde nitelikli sürdürülebilir tarımsal üretimin gelişmesi fayda sağlayacaktır.

Bu çalışmada, kent çeperi ve kırsalında organik bitkisel üretimin mekânsal-yapısal özelliklerini anlamak amacıyla Bursa Metropolü ele alınmıştır. Hem tarım hem de sanayi sektöründe ön plana çıkan il, Türkiye’nin nüfus açısından dördüncü büyük kentidir. Lojistik bağlantıların kuvvetli olduğu Bursa’da organik tarım uygulamalarını teşvik etmek, bariyerleri tespit ederek geliştirilecek politikalara yön vermek amacıyla mevcut yapı sorgulanmıştır. Türkiye’de organik tarımın genel durumunu ve iller bazında irdelemeleri içeren araştırmalar olmakla birlikte kent-yakın çevre ilişkisini ve çiftçilerin tarıma devam etme eğilimini sorgulayan ulusal çalışmalara rastlanmamıştır. Bu

haliyle ilgili çalışmanın yere özgü tarımsal politikaların geliştirilmesi için önemli bir altlık sağlayacağı düşünülmektedir. Bu doğrultuda girişten sonraki bölümde kent çeperi- yakın kırsalında organik tarım uygulamalarına ve organik tarımın sürdürülebilirliğine yer veren araştırmalardan elde edilen genel çıkarımlar sunulmuştur. Üçüncü bölümde materyal ve yöntem açıklanmıştır. Çalışmada ikincil veri kaynakları ve organik üreticilerle yapılan anket çalışmasıyla elde edilen birincil veriler kullanılmıştır. Bursa'da organik üretimin mekânsal deseni çıkartılmış, organik tarımı icra eden üreticilerin ve işletmelerin yapısal özellikleri anlaşılmış, daha sonra bu özelliklerin organik tarıma devam etmedeki etkisi karar ağacı modeliyle sorgulanmıştır. Dördüncü bölümde analiz çalışmalarından elde edilen bulgular aktarılmıştır. Sonuç bölümünde çalışmanın çıkarımları, ilgili yazınla birlikte ele alınarak tartışılmıştır.

## **2. Yerel Gıda Sistemleri, Kent Çeperi ve Yakın Kırsalında Organik Tarım ve Sürdürülebilirliği**

### **2.1 Yerel Gıda Sistemleri, Kent Çeperi- Yakın Kırsalında Organik Tarım Faaliyetlerinin Önemi**

Gıda güvenliği, yıllardır tartışıl原因 Birleşmiş Milletlerin Sürdürülebilir Kalkınma Amaçları çerçevesinde uluslararası politikalarda hem yoksullukla ilişkilendirilerek hem de tarımın sürdürülebilirliği bağlamında değerlendirilen öncelikli temel sorunlardan biridir. Organik tarım; sentetik gübreler, böcek ilaçları ve genetik olarak değiştirilmiş organizmalar (GDO'lar) gibi kimyasal maddelerin kullanımını sınırlamayı hedefleyen, belli standartlar çerçevesinde konvansiyonel üretim şekillerine alternatif olarak geliştirilmiş üretim yöntemlerinden biridir (Yolcu ve Tan, 2008). Uluslararası Organik Tarım Hareketi Federasyonu (IFOAM) organik tarımı insan sağlığını ve ekosistemi koruyan, girdi kullanımı yerine yerel koşulları ve biyolojik çeşitliliği önceliklendiren, çevreye fayda sağlayan ve paydaşlar arasında adil ilişki ve iyi bir yaşam kalitesine odaklanan geleneksel yöntemlerle teknolojiyi ilişkilendiren bir üretim biçimi olarak tanımlamaktadır (IFOAM, 2008). Bu üretim biçiminin, toprağın doğal besin maddeleriyle zenginleştirilmesi ve sağlıklı mikroorganizmaların varlığını teşvik ederek, uzun vadede verimliliği artıracak iddia edilmektedir. Sentetik gübreler ve pestisit gibi kimyasal maddelerin kullanımı, tarım atıklarının su kaynaklarına sızmasına ve su kirliliğine, ayrıca tarım alanlarında yaşayan doğal bitki ve hayvan türlerinin zarar görmesine neden olabilir (Atasever ve Adıgüzel, 2006). Organik tarım yöntemleri ise doğal yaşam alanlarını ve biyoçeşitliliği destekleyerek doğal ekosistemlerin korunmasına katkıda bulunmaktadır. Aynı zamanda organik tarım, iklim değişikliğiyle mücadelede olumlu bir rol oynama potansiyeline sahiptir. Sürdürülebilir toprak yönetimi ve yenilenebilir enerji kaynaklarının kullanımı gibi unsurlar ile birlikte değerlendirildiğinde sera gazı emisyonlarının azaltılmasına katkı sağlayabilir (Avrupa Komisyonu, 2023).

Son 10 yıllık süreçte dünyada yerel gıda sistemlerinin daha kapsayıcı, dayanıklı ve sürdürülebilir olduğu iddiasıyla gelişiminin önceliklendirildiği görülmektedir (Enthoven ve Broeck, 2021). Uzlaşmış bir tanımla olmamakla birlikte yerel gıda sistemleri, sınırlı bir coğrafyada gerçekleştirilen üretim, işleme, satış süreçlerini ifade etmektedir (Kneafsey ve ark., 2013). Yazında; üretim, tüketim, sistemde yer alan aktörler arası yakınlık üzerinden gıdanın yerelliği tartışılmaktadır (Enthoven ve Broeck, 2021; Eriksen, 2013). Bu araştırmalarda; aktörler arası mesafenin önemine değinilerek, kısa tedarik zincirlerinin, konvansiyonel tarım uygulamalarının çevresel etkilerini minimize etme potansiyeli taşıdığı belirtilmektedir (Renting ve ark., 2003; Marsden ve ark., 1999; Murdoch ve ark., 1999). Mevsiminde yetişen, yerel olarak üretilen gıdaya artan ilgiyle birlikte metropol çevresi kırsal alanlardaki üreticilerle, kentte yaşayan tüketicileri bir araya getirme çabası da artış göstermiştir. Bu çaba, üretici ve tüketici arası doğrudan ilişkiye olanak sunan, kır-kent bağlantısını kuvvetlendiren bir mekanizma geliştirmeyi sağlayabilir (Renting ve ark., 2003). Günümüzde konvansiyonel üretim yöntemlerinin tarım topraklarında yaratmış olduğu kirlilik ve kentleşme ile üretim alanlarının yapay fonksiyonlara konu olmasının gıda güvenliğini tehdit ettiği görülmektedir. Bu baskının yarattığı negatif etkilerden sıyrılmak amacıyla yazında kente yakın alanlarda kır-kent ve kent-çeper ilişkisini kuvvetlendirecek sürdürülebilir gıda üretimi uygulamalarının önemi vurgulanmaktadır (Yacamán Ochoa ve ark. 2020). Yerel gıda sistemlerine atıfla, üretim ve tüketimin bir aradalığı üzerinden gelişen kent çeperinde tarım olgusu, kentlerin etrafındaki alanlarda insan gücü, ürün ve hizmetlerden yararlanarak üretim faaliyetlerinin gerçekleştirilmesi ve bu ürünlerin yine yakın çevresindeki kentler tarafından kullanımını içeren bir üretimi ifade etmektedir (Mougeot, 2000). Kente yakın bölgelerde gıda üretiminin sağlanması, kısa tedarik zinciri aracılığıyla gıdanın tazeliğini koruyarak ve çok mesafe kat etmeden yerel pazarlarda sunulmasını kolaylaştıracaktır. Ek olarak kentlerin gıda taleplerinin karşılanmasında yakın çeperindeki tarım alanlarında üretimin ve doğrudan kurulan ilişkinin kent-çeper bütünleşmesine aracılık edebileceği, süreçte



yer alan aktörler tarafından yaratılan değerın sosyal paylaşımının bu üretime dahil olan kırsal karakterli yerleşimlerin kalkınmasına katkı sağlayacağı iddia edilmektedir (Renting ve ark., 2003).

Kent çeperinde organik tarım ise kentleşme baskısının ve konvansiyonel üretimin yaratmış olduğu tarım topraklarında bozulmanın önüne geçebilecek bir üretim yöntemi olarak doğal yaşamın çeşitliliğini koruyarak ekosistemi destekleme potansiyelini barındırmaktadır (FAO ve ark. 2022). Organik tarım ve kent ilişkisini sorgulayan araştırmalarda organik üretimin hem ekonomik hem de ekolojik açıdan faydaları ve tarımın sürdürülebilirliği için bu üretim türünün önemli olduğu vurgusu yapılmaktadır. Örnekle, Pérez-Neira ve Grollmus-Venegas (2018) İspanya Seville kent çeperinde organik tarım ve konvansiyonel tarımı enerji tüketimi ve karbon ayak izi açısından karşılaştıran bir araştırma gerçekleştirmişlerdir. Çalışmanın sonuçlarına göre organik üretimin konvansiyonel yöntemle göre kilogram başına yaklaşık %42.5 daha az yenilenemeyen enerji tükettiği, doğrudan dağıtım kanallarının ise yerel gıda tedarik zincirlerine göre %63.8 ile %91.3 arası sera gazı salınımını azalttığı belirtilmektedir. İlgili araştırma sonucunda tüketiciye daha yakın olan kent çeperinde organik üretim yapmanın ekonomik açıdan daha verimli ve sürdürülebilir olduğu ortaya konmuştur.

Kent yakın çevresi kırsalında ve çeperinde gerçekleştirilen organik tarım faaliyetlerinin; organik atıkların gübre olarak kullanılabilmesi, çeperin daha sürdürülebilir olması, kentsel nüfusun gıda gereksiniminin bir kısmının karşılanması, mikro iklim koşullarının iyileştirilmesi, kısa tedarik zincirleriyle (taşımacılık mesafelerinin kısılması vb.) kentin ekolojik ayak izinin azalması gibi yararları olduğu ifade edilmektedir (Bhatta ve Doppler, 2011). Bu potansiyelleri değerlendirerek, kentlerin yakın çevresinde organik tarımın gelişiminin desteklenmesi için FAO (2022a) bazı öneriler geliştirmiştir. Organik tarım için kent içinde ve çevresindeki boş arazilerin kullanımını kolaylaştırma ve teşvik etme, organik üreticilerin pazarlama-dağıtım olanaklarını artırma, kent halkını organik tarım konusunda bilinçlendirecek eğitim programları düzenleme gibi stratejilerin üretimi destekleyeceği öngörülmüştür. Organik tarımsal üretime dayalı yerel gıda sisteminin oluşturulması ve devamlılığını sağlamak için konvansiyonel üretim süreçlerinden farklı makro ve mezo ölçekte kurumsal, mekânsal, organizasyonel stratejiler üretilmesi gerekmektedir. Bu eylemler, organik tarıma geçiş ve sürdürülmesinde kamu teşviklerini, çiftçilerin beşeri sermayelerini geliştirmeye yönelik eğitim, araştırma ve teknoloji kullanımını artıracak proje ve programları, kısa tedarik zincirlerini destekleyecek (organik tarıma özgü pazarlar, depolama çözümleri, sivil dayanışma vb.) yatırım kararlarını içerebilir. Birçok araştırma kamu desteğinin çiftçilerin organik tarım pratiklerine geçiş ve pratiği sürdürmesinde önemli bir mekanizma olduğunu belirtmektedir (Yadava, 2024). Bu bağlamda organik tarım pratiğinin devam etmesini sağlayan unsurlar aşağıda daha kapsamlı bir şekilde tartışılmaktadır.

### 2.3 Organik Tarımın Sürdürülebilirliği

Kent çeperinde organik tarım faaliyetlerinin yarattığı olumlu etkileri, yazındaki alan çalışmalarından izlemek mümkündür. Fakat üretimin devamlılığını sağlamak için, bu eğilimi etkileyen faktörleri belirlemek de önemli bir konu olarak karşımıza çıkmaktadır. 2000’li yıllardan itibaren organik tarıma geçişi etkileyen faktörlerin sıklıkla çalışıldığı görülmektedir. Bu çalışmalar incelendiğinde ağırlıklı olarak organik tarıma geçiş konusuna iki farklı ölçekten yaklaşıldığı görülmüştür. Bazı çalışmalar mikro ölçekten çiftçiye odaklanarak bireysel tutum ve davranışları incelerken, makro düzeydeki araştırmalarda ise politika, ekonomi, teknoloji, sosyal çevre, kurumsal yapı ve piyasa gibi yapısal faktörlerin organik tarımın gelişmesini nasıl etkilediği üzerinde durulmaktadır (Cakirli Akyüz ve Theuvsen, 2020; Darnhofer, 2005; Läßle ve Rensburg, 2011; Burton, 2004; Firdauzi ve ark., 2024; Huttunen ve Oosterveer, 2017; Duram, 2000). Son 20 yıllık süreçte dünyada organik tarımsal üretimde iniş çıkışlı bir büyüme olduğu izlenmektedir. Yeni geçiş yapan üreticilerin yanı sıra mevcut üreticiler arasında vazgeçenlerin bulunması organik tarımın dalgalı seyir izleyerek gelişmesine neden olmaktadır. Bu durum üreticilerin devamlılığıyla ilgili bir sorun olduğuna işaret etmektedir. İlgili yazında bu yönde çalışmalar olmakla birlikte, bağlamın önemli olduğu vurgusu yapılmaktadır (Darnhofer ve ark., 2019; Sahm ve ark., 2013).

Macombe (2007), Fransa’da alternatif tarım yapan çiftçilerin üretimi aileden devralma ve bir yaşam projesi olarak görmesi gibi koşulların faaliyeti sürdürmelerinde önemli olduğunu iddia etmektedir. Luczka ve ark. (2021), Polonya’da organik tarım faaliyetlerinin devamlılığında finansal destek mekanizmalarının etkisini vurgulamaktadır. Fakat bu destek sistemlerinin belli bir aşamadan sonra çiftçilerin devlet politikalarına ve bu politikaların istikrarlılığına bağımlı hale gelmesine sebep olabileceğini belirtmektedir. Vittersø ve ark. (2019), kısa tedarik zincirlerinin ekonomik ve çevresel katkısı bağlamında alternatif tarımsal üretimi desteklemede etkili olduğuna değinir. Diğer taraftan tarımsal üretimde verimliliği ve üretim maliyetlerini etkileyen ölçek konusunun

organik tarımsal üretimde de önemli olduğu görülmektedir. Zuba-Ciszewska ve ark. (2023), Polonya’da organik süt üretimi sektörünü inceledikleri araştırmalarında üretici ve işleyenler arasında işbirliğinin gerekli olduğunu vurgulamaktadır. Üretim, piyasa konusunda eğitim ve teknik desteğin de önemli olduğu belirtilmekte, doğası gereği sözleşmeli – alma garantili üretimin sektörün devamlılığı ve büyümesi için öncelikli olduğu ifade edilmektedir. Darnhofer ve ark. (2019), İtalya, Avusturya ve Fransa örnekleri üzerinden organik tarımın gelişiminde etkili faktörleri ele aldıkları araştırmalarında Avusturya’da üreticiye doğrudan ödenen teşviklerin önemli olduğunu fakat tek başına sektörün gelişimini açıklayamayacağını belirtir. Organik tarımda geleneksel üretime bağlı kalma, yerel organik gıdaya olan tüketici talepleri vb. faktörlerin de birleşerek katkı sağladığı ifade edilmektedir. Organik üretiminin gelişimine etki eden faktörleri üretici ve üretimin yapısal özellikleriyle ilişkilendiren araştırmalar da bulunmaktadır. Çiftçilerin elde ettiği gelir (Flaten ve ark., 2010; Läßle, 2010; Harris ve ark., 2008; Sahm ve ark., 2013; Zuba-Ciszewska ve ark., 2023), üretici yaşı (Matysiak, 2021; Brodziak, 2017; Zuba-Ciszewska ve ark., 2023), üretim kapasitesi (Łuczka, 2017; Zuba-Ciszewska ve ark., 2023) ve işletme ölçeği (Sahm ve ark., 2013; Rigby ve ark., 2001), sertifikasyon ve kontrol süreçlerinde yaşanan problemler (Harris ve ark., 2008; Sahm ve ark., 2013; Kaltoft ve ark., 2006) teknik vb. bilgiye erişim sıkıntıları (Rigby ve ark., 2001; Ploomi ve ark., 2006) organik tarıma devam etmede etki eden faktörler olarak sıralanmaktadır.

Bu bağlamda çalışma, kent çeperi ve yakın kırsalında gerçekleştirilen organik tarım faaliyetlerinin durumunu anlamak amacıyla üretimin coğrafyasını betimlemiş ve organik tarımın devamlılığının sağlanmasında çiftçi ve çiftlik yapısal özelliklerinin etkisini Bursa ili örneği üzerinden incelemiştir. Çalışmanın yöntem ve bulgularına aşağıda yer verilmektedir.

### 3. Materyal ve Metot

Araştırma, Bursa’da organik üretimin mekânsal özelliklerini tespit etmeyi ve organik tarımın devamlılığını etkileyen üretici ve üretime dair mikro ölçekli yapısal faktörleri belirlemeyi hedeflemektedir. Bu bağlamda, çalışmanın dayanağını iki farklı veri türü oluşturmaktadır. Mekansal betimleyici analizlerin gerçekleşmesinde Bursa İl Tarım ve Orman Müdürlüğü 2021 yılı Organik Tarım Bilgi Sistemi’nden (OTBİS) yararlanılmış ve ArcGIS Pro programı kullanılarak organik tarımın Bursa’daki coğrafi yapısı incelenmiştir. Ek olarak, 13 ilçe ve 46 köy ziyaret edilerek ve yerinde erişilerek OTBİS veri tabanına kayıtlı olan 115 üreticiyle (toplam organik bitkisel üreticilerin %85.2’si) Eylül- Ekim 2022 tarihlerinde anket çalışması gerçekleştirilmiştir. Tam sayım yöntemiyle planlanan çalışmada 2022’de OTBİS’e kayıtlı toplam 135 üreticinin 3 tanesinin organik tarımı bıraktığı tespit edilmiş, 17’sine de ulaşılamamıştır. Anket çalışması sonucu elde edilen organik tarım yapan üreticilerin sosyo-demografik özellikleri, üretim yapısı ve çiftçilerin organik bitkisel üretime devam etme eğilimleri arasındaki ilişkiyi incelemek için SPSS 22 programı aracılığıyla karar ağacı modeli CRT (classification and regression tree) metodu kullanılmıştır. Karar ağacı modeli belirlenen karar kurallarına göre gelecekteki gözlemleri regresyona dayalı tahmin eden ya da sınıflandıran parametrik olmayan bir analiz türüdür (IBM, 2024). Organik tarıma devam etmede etkili olan faktörler çiftçilerin sosyo-demografik özellikleri ve üretimin yapısal özellikleri üzerinden değerlendirilmiştir. Çiftçilerin sosyo-demografik özelliklerinin üretime devam etmelerindeki etkisini incelemek üzere aşağıdaki hipotezler geliştirilmiştir:

H<sub>1</sub>: Çiftçilerin yaşı, organik tarıma devam etme eğilimlerini etkilemektedir.

H<sub>2</sub>: Çiftçilerin eğitim durumu, organik tarıma devam etme eğilimlerini etkilemektedir.

H<sub>3</sub>: Çiftçilerin tarım eğitimi alma durumu, organik tarıma devam etme eğilimlerini etkilemektedir.

H<sub>4</sub>: Çiftçilerin kooperatif veya dernek üyesi olma durumu, organik tarıma devam etme eğilimlerini etkilemektedir.

Üretimin yapısal özelliklerinin çiftçilerin organik üretime devam etme eğilimine katkısını anlamak amacıyla geliştirilen hipotezler de aşağıda sıralanmıştır:

H<sub>5</sub>: Organik bitkisel üretim yapılan işletme büyüklüğü, çiftçilerin organik tarıma devam etme eğilimini etkilemektedir.

H<sub>6</sub>: Organik bitkisel üretim yapılan işletmenin parçalı olma durumu, çiftçilerin organik tarıma devam etme eğilimini etkilemektedir.

H<sub>7</sub>: Çiftçilerin sözleşmeli tarım yapma durumu, organik tarıma devam etme eğilimlerini etkilemektedir.

H<sub>8</sub>: Çiftçilerin tarımsal destek alma durumu, organik tarıma devam etme eğilimlerini etkilemektedir.

H<sub>9</sub>: İşletmede yetiştirilen ürün çeşitliliği, çiftçilerin organik tarıma devam etme eğilimlerini etkilemektedir.

H<sub>10</sub>: Çiftçilerin organik tarımla uğraşma süreleri, organik tarıma devam etme eğilimlerini etkilemektedir.

H<sub>11</sub>: Çiftçilerin organik tarımdan elde ettikleri gelir, organik tarıma devam etme eğilimlerini etkilemektedir.

Karar ağacı modeli için kullanılan bağımlı ve bağımsız değişkenler, hipotezlerin de dayanağı olan organik tarıma devam etme eğilimini ele alınan araştırmalarla ilişkilendirilerek *Tablo 1*'de ifade edilmiştir. Bağımlı değişken, çiftçilerin organik tarımla ilgili gelecek planları ve eğilimleri üzerinden değerlendirilmiştir.

Değişkenler oranlı ölçekte toplanmış olsalar dahi ağırlıklı ortalama değere göre kategorik olarak sınıflandırılmıştır (ortalama değer altı ve üstü olarak). Organik tarıma devam etme eğilimi, likert ölçeğinde değerlendirilen soruların ağırlıklı ortalaması alınarak hesaplanmıştır. Cevapların birleştirilmesinde Cronbach Alfa İç Tutarlılık Katsayısına bakılmıştır (0,6). Sonuç olarak ağırlıklı ortalamanın üzerinde olan değerler yüksek devam etme eğilimi, altında olan değerler ise düşük devam etme eğilimi olarak sınıflandırılmıştır.

**Tablo 1. Bağımlı ve Bağımsız Değişkenler**

*Table 1. Dependent and Independent Variables*

| Bileşenler                                                      | Değişkenler                                      | Anket sorusu                                                                                                | Kaynak                                                                                                          |
|-----------------------------------------------------------------|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| Çiftçilerin sosyo-demografik özellikleri (bağımsız değişkenler) | Yaş                                              | Yaşınız?                                                                                                    | Matysiak (2021); Brodziak, (2017); Zuba-Ciszewska ve ark. (2023)                                                |
|                                                                 | Eğitim Durumu                                    | Eğitim Durumunuz?                                                                                           | Rigby ve ark. (2001); Ploomi ve ark. (2006)                                                                     |
|                                                                 | Tarım eğitimi                                    | Tarımla ilgili herhangi bir eğitim aldınız mı?                                                              | Kumar ve ark. (2018); Candemir ve ark. (2021), Yu ve ark. (2021); Ma ve ark. (2018)                             |
|                                                                 | Dernek-kooperatif üyeliği                        | Tarımla ilgili bir kooperatife/derneğe üye misiniz?                                                         |                                                                                                                 |
| Üretimin yapısal özellikleri (bağımsız değişkenler)             | İşletme büyüklüğü ve arazi parçalılığı           | Toplam tarım alanınızın büyüklüğü kaç dönümdür?<br>Organik üretim yaptığınız arazi parçalı mı / dağınık mı? | Sahm ve ark. (2013); Rigby ve ark. (2001)                                                                       |
|                                                                 | Sözleşmeli tarım                                 | Sözleşmeli tarım yapıyor musunuz?                                                                           | Zuba-Ciszewska ve ark. (2023)                                                                                   |
|                                                                 | Tarımsal destek                                  | Şimdiye kadar organik tarımla ilgili herhangi bir kurumdan destek aldınız mı?                               | Luczka ve ark. (2021); Darnhofer ve ark. (2019)                                                                 |
|                                                                 | Ürün çeşitliliği                                 | Toplam kaç çeşit organik ürün yetiştiriyorsunuz?                                                            | Łuczka, (2017); Zuba-Ciszewska ve ark. (2023)                                                                   |
|                                                                 | Organik tarımla uğraşma süresi                   | Kaç senedir organik tarımla uğraşıyorsunuz?                                                                 | Rigby ve ark. (2001); Ploomi ve ark. (2006)                                                                     |
|                                                                 | Tarımdan elde edilen gelir                       | Geçen yıl (2021 yılında) organik üretimden ne kadar gelir elde ettiniz?                                     | Flaten ve ark. (2010); Läpple (2010); Harris ve ark. (2008); Sahm ve ark. (2013); Zuba-Ciszewska ve ark. (2023) |
|                                                                 |                                                  |                                                                                                             |                                                                                                                 |
| Organik tarıma devam etme eğilimi (bağımlı değişken)            | Toprağını elden çıkarma eğilimi                  | Tarım toprağıma istediğim fiyatı verirlerse satmam.                                                         |                                                                                                                 |
|                                                                 | Gelecek neslin organik tarıma devam etme eğilimi | Benden sonra çocuklarım, çiftliği aynı şekilde devam ettirecektir.                                          |                                                                                                                 |
|                                                                 | Organik tarım piyasasına güven                   | Organik tarım piyasası giderek büyüyor; gelecek vad ediyor.                                                 |                                                                                                                 |
|                                                                 | Maddi desteklere bağlı devam etme eğilimi        | Desteklemeler (ucuz kredi, vergi iadesi, teşvik ödemesi gibi) olursa organik tarımı geliştirebilirim.       |                                                                                                                 |

#### 4. Araştırma Bulguları

##### 4.1. Bursa'da Organik Bitkisel Üretim Faaliyetlerinin Coğrafi Yapısı

Bursa İl Tarım ve Orman Müdürlüğü 2021 yılı verilerinde organik bitkisel tarım yapan 135 üretici bulunmaktadır. Üreticilerin farklı mahallelerde arazi sahipliği nedeniyle bu sayı yerleşim bazında değerlendirildiğinde 159 üretim yerine işaret etmektedir. İlçe ve mahalle bazında verilen istatistiklerde ve haritalarda üretim yerine göre değerlendirme gerçekleştirilmiştir. Çiftçilerin ilçelere göre dağılımına bakıldığında toplam sayının %48'inin Keles, %13'ünün İnegöl'de yoğunlaştığı görülmektedir. Bu ilçeleri Osmangazi (%8), Büyükşehir (%7) ve Kestel (%6) izlemektedir (Şekil 1). İlgili veri kapsamında toplam sayının %54'ünü geçiş dönemi, %45'ini ise organik üreticiler oluşturmaktadır. Orhangazi ve Gemlik'te üretici sayıları 1 ile sınırlı olup her iki üretici de geçiş dönemindedir. Mudanya, Gürsu, Yıldırım ve Harmancık'ta ise organik bitkisel tarım yapan üreticilerin bulunmadığı görülmektedir.

Aynı veri üzerinden üretim alanı büyüklükleri değerlendirildiğinde organik bitkisel üretim alanının en fazla olduğu ilçenin %77.8 ile Karacabey (12365 da.) olduğu izlenmektedir. Bu ilçeyi Keles (%7.8, 1236 da.), Yenişehir (%5.6, 896 da.) ve İnegöl (%1.9, 307 da.) takip etmektedir. Gemlik, Orhangazi ve Orhanlı'nda organik üretim yapılan tarımsal alan büyüklüğü ise diğer ilçelere göre daha azdır. Fakat Karacabey'de büyük tarımsal alan varlığına karşılık üretici sayısı düşüktür. İlgili istatistiklerde yer alan, organik bitkisel üretim miktarı büyüklüklerine göre ilçelerin aldığı paylara bakıldığında sırasıyla Kestel (%91.86), Karacabey (%3.01), Yenişehir (%2.03) ve Keles (%1.85) ilçeleri ön plana çıkmaktadır. Kestel üretim alanı büyüklüğü açısından Karacabey'e kıyasla çok daha küçük bir paya sahip olmakla birlikte tahmini üretim miktarı en fazla olan ilçe olarak gözükmektedir. İlçe bazında çiftçi başına düşen üretim alanı büyüklüklerinde Karacabey (2472.96 da.), Yenişehir (298.53 da.) il ortalamasının (100 dekar) üzerinde kalan ilçelerdir. Çiftçi başına üretim alanının en küçük olduğu ilçeler ise Osmangazi (8.05 da.), Büyükşehir (9.45 da.) ve Orhanlı'dır (12.51 da.). Karacabey'de üretici başına düşen alanda bu kadar yüksek bir rakam çıkmasının temel nedeni tek bir üreticiye ait büyük miktardaki organik tarımsal alanın varlığından kaynaklanmaktadır.

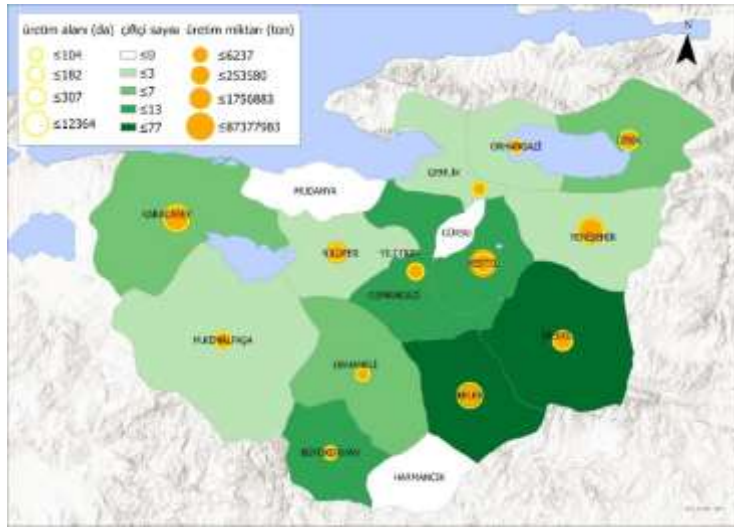


Figure1. Distribution of organic production, farm size and farmers by districts according to quartiles (prepared by the authors based on the statistics of Bursa Provincial Directorate of Agriculture and Forestry 2021).

**Şekil 1. Organik bitkisel tarım yapan üreticilerin, üretim miktarının ve üretim alanlarının ilçelere göre kartil dağılımı (Bursa İl Tarım ve Orman Müdürlüğü 2021 verileri kullanılarak yazarlar tarafından üretilmiştir).**

Bursa'da 2021 yılı OTBİS kayıtlarına göre organik bitkisel üretimin 62 mahallede gerçekleştiği görülmektedir. Organik bitkisel üretim yapan çiftçi lokasyonlarının mahallere göre dağılımına bakıldığında Keles ilçesinde; Delice (24), Kocakovacık (12), Yazıbaşı (11), Gököz (9), Osmangazi'de Soğukpınar (8), İnegöl'de Mesruriye (7) mahalleri öne çıkmaktadır. İşletmelerin coğrafi konumları organik bitkisel üretimin genel olarak kent merkezinden uzak, topoğrafik açıdan yüksek rakımlı arazilerde yoğunlaştığını göstermektedir. Keles, İnegöl, Osmangazi, Büyükşehir, Orhangazi, Orhanlı, Mudanya, Gürsu, Yıldırım ve Harmancık'ta ise organik bitkisel tarım yapan üreticilerin bulunmadığı görülmektedir.



İznik ve Kestel'de birbirine yakın konumdaki mahallelerde üretimde yığılma eğiliminin, diğer ilçelerde ise mahalle bazında daha dağınık bir yapının var olduğu görülmektedir (Şekil 2).

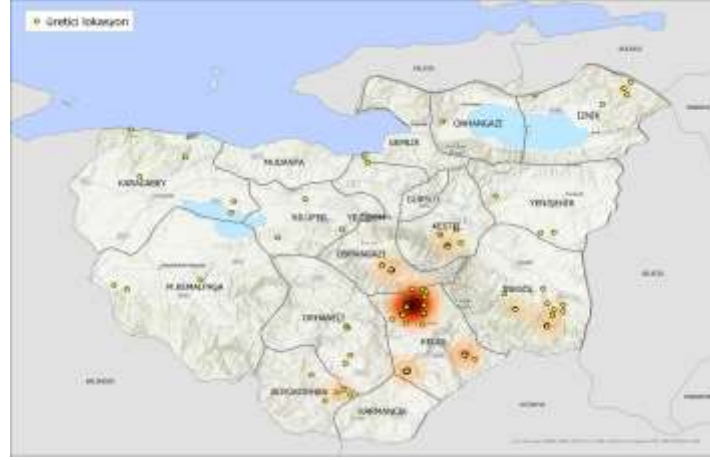


Figure 2. Spatial distribution of organic farmers (kernel density analysis) (prepared by the authors based on the statistics of Bursa Provincial Directorate of Agriculture and Forestry 2021).

**Şekil 2. Organik üreticilerin mekansal dağılımı (kernel yoğunluk analizi) (Bursa İl Tarım ve Orman Müdürlüğü 2021 istatistiklerinden yararlanılarak yazarlar tarafından üretilmiştir).**

İlde organik üretim alanlarının büyüklüklerine bakıldığında, küçük parsellerin hakim olduğu parçalı bir yapı tespit edilmiştir. Organik bitkisel üretim yapan çiftçilere ait toplam 520 parselden oluşan yaklaşık 16168 dekarlık alanın, 15898 dekarında (%98.3) organik üretim gerçekleştirilmektedir. Parsel büyüklükleri; 0,1 da. ile 11500 da. aralığında değişmektedir. Parsellerin %50'si 4,8 da., %75'i ise 8.4 da. büyüklüğün altındadır. En büyük üretim alanları Karacabey Ekmekçi (11480.864 da.) ve Kurşunlu'da (566.737 da.) yer almaktadır. Bu iki mahalledeki ilgili üretim alanları tek parselden oluşmaktadır. Fakat diğer mahallelerde genel olarak organik tarım alanlarının küçük ve birden çok parselden oluşan üretim alanlarından meydana geldiği söylenebilir. Örnek olarak üretici sayısının yüksek olduğu Keles İlçesi Delice Mahallesi'nde 369,559 da.'lık üretim alanı 81 parsel, Kocakovacık Mahallesi'ndeki 419096 da. alandaki üretim ise 99 parsel dağılmıştır (Şekil 3).

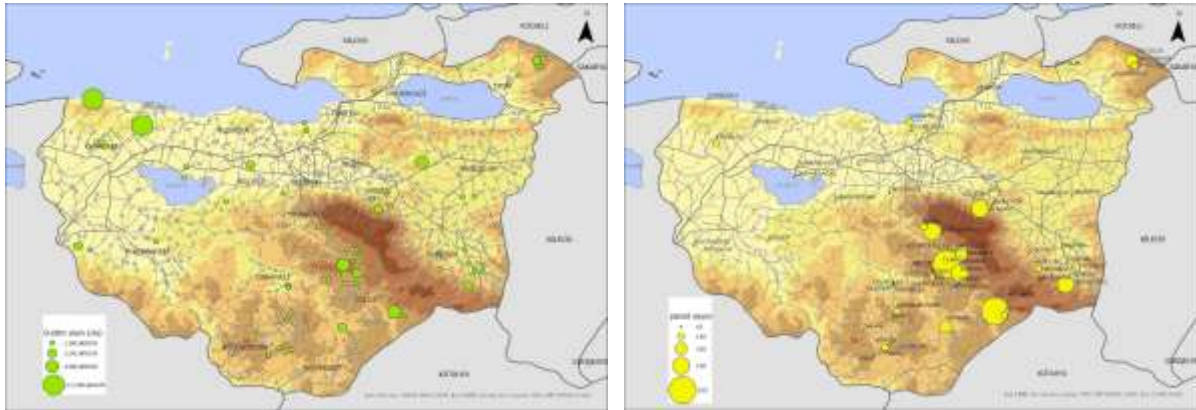


Figure 3. Distribution of organic production area size (left) and number of parcels (right) by neighbourhoods (da)

**Şekil 3. Mahallelere göre organik üretim alanı büyüklüğü (solda) ve parsel sayısı (sağda) dağılımı (da)**

Sonuç olarak, Keles, İnegöl, Osmangazi, Büyükşehir ilçe üretici sayısı açısından ön plana çıkarken, üretim alanı büyüklüklerine göre Karacabey ilçesi önem kazanmaktadır. Üretim miktarına bakıldığında Keles ilde en fazla üretimin (ilin %91'i) gerçekleştiği ilçedir. Çiftçi başına düşen üretim alanında ise Karacabey en büyük rakama sahiptir. İlçede Kurşunlu ve Ekmekçi Mahallesi'nde iki büyük işletme bulunmaktadır. Keles'de üretim miktarı ve çiftçi sayısı yüksek olmakla birlikte işletmelerin ölçek olarak küçük olduğu görülmektedir. Üretici sayısının yüksek olduğu

ilçelerde organik bitkisel üretimin daha çok dağlık alanlarda, konvansiyonel üretimin daha az olduğu, ilaçlama gerektirmeyen çilek, ahududu, yaban mersini gibi ürünlere dayalı gerçekleştirildiği söylenebilir. Uludağ yakın çevresinde daha çok küçük ölçekli parçalı işletmelerin kümелendiği anlaşılmaktadır. Keles, Osmangazi, Kestel, İnegöl'ün çeşitli mahallelerinde doğal eşikler, kent kirleticilerinden uzak arazilerde organik ürün yetiştirmek adına fırsat sağlamaktadır. Fakat bu eşikler nedeniyle pazara erişimin, üretim kapasitesi düşük, küçük ölçekli işletmeler için önemli bir maliyet kaynağı olacağı görülmektedir. Dağ yerleşmelerindeki çiftçilerin sözleşmeli tarıma yönelmesinde pazara erişim sıkıntısının etkili olduğu anlaşılmaktadır. Düzlik arazilerin sağladığı avantajla Karacabey'de daha büyük işletmelerde organik üretim gerçekleştirmekle birlikte bu işletmelerin sayısı azdır. Bu temel mekânsal bulgulara ek olarak, gerçekleştirilen anket çalışması kapsamında üretici ve üretimin yapısına dair tespit ve değerlendirmeler aşağıdaki bölümde yer almaktadır.

#### 4.2. Bursa'da Organik Tarımın Sürdürülebilirliğini Etkileyen Yapısal Faktörler

İlde 115 üreticiyle gerçekleştirilen anket çalışması ile üretici ve üretime dayalı temel yapısal özellikler tespit edilmiştir (Tablo 2 ve 3). Bursa'da organik tarım üreticilerinin yaş ortalamasının 57.5 olduğu (SD=10.53) görülmektedir. 20-39 yaş arası genç üretici sayısı %7 olmakla birlikte çiftliklerde genelde aile üyelerinin de çalıştığı tespit edilmiştir. Türkiye'de genel olarak tarım üretiminde ortalama yaşın 51 olduğu görülmektedir (KKB, 2020). Eğitim durumuna bakıldığında %89'u lise altı eğitim kurumlarından mezun olmuşlardır. Tarımla ilgili herhangi bir eğitim alan çiftçi sayısı %39.1'dir. %66'sının tarımla uğraşma süresi 30 yılın üzerindedir. Organik tarım öncesi üreticilerin %76,5'i konvansiyonel üretim gerçekleştirmektedir. Sertifikalı olarak organik üretim faaliyetleri gerçekleştirme sürelerine bakıldığında 1-14 yıl arası üretim yapan oranı %35.7'dir. Bu soruyu yanıtsız bırakanların oranı ise %40.9'dur. Bir kooperatif ya da derneğe üye olan çiftçi oranı %86.1 olmakla birlikte, bu üyeliğin Ziraat Odası (%68.7), Köy Kalkınma Kooperatifi (%16.5) ve İlçe Tarım Kredi Kooperatifi (%7) olduğu görülmektedir.

**Tablo 2. Anket çalışmasından elde edilen çiftçi özellikleri**

*Table 2. Characteristics of farmers obtained from the questionnaire*

| Değişken                     | Kategori              | Frekans | %    |
|------------------------------|-----------------------|---------|------|
| Cinsiyet                     | Kadın                 | 7       | 6.1  |
|                              | Erkek                 | 108     | 93.9 |
| Yaş                          | 20-39                 | 8       | 7    |
|                              | 40-59                 | 55      | 47.8 |
|                              | 60 ve üstü            | 52      | 45.2 |
| Eğitim durumu                | Okul bitirmemiş       | 2       | 1.7  |
|                              | Lise altı             | 87      | 75.7 |
|                              | Lise ve meslek lisesi | 8       | 7    |
|                              | Yüksekokul ve üstü    | 9       | 7.8  |
|                              | Yanıtsız              | 9       | 7.8  |
| Tarım eğitimi                | Evet                  | 45      | 39.1 |
|                              | Hayır                 | 70      | 60.9 |
| Tarımla uğraşma süresi (yıl) | 2-10                  | 6       | 5.2  |
|                              | 11-20                 | 10      | 8.7  |
|                              | 21-30                 | 22      | 19.1 |
|                              | 30 üstü               | 76      | 66.1 |

Üreticilerin sahip olduğu arazi büyüklüklerine bakıldığında genel olarak 20-49 dekar arası grubun daha büyük pay aldığı görülmektedir (%42.6). Ortalama tarım alanı büyüklüğü ise 56.6 dekadır. 2016 yılı verilerine göre Türkiye'de 20-49 dekar arası işletme büyüklüğü grubu %25.9 pay almaktadır (TÜİK, 2016). Bursa'da organik tarım üretimi yapılan alan büyüklüklerinde daha farklı bir tablo izlenmektedir. Ayrıca, çiftçilerin organik tarım üretimi yaptıkları alanların, arazilerinin sınırlı bir kısmını içerdiği görülmektedir.

Arazi parçalılığı incelendiğinde çiftçilerin %83.5'i parçalı araziye sahip olduklarını belirtmişlerdir. Parça sayısına bakıldığında genel olarak 1-5 arası kategorinin %54.8'lik bir paya sahip olduğu görülmektedir. Yine 2016 yılı TÜİK verilerine göre Türkiye'de tarım arazisi parça sayısı incelendiğinde işletme başına düşen parça sayısının 5.9 adet olduğu hesaplanmıştır. Benzer şekilde Bursa'da organik üretim yapan işletme başına parça sayısı 5.6'dır. Tarım arazisi mülkiyet durumunda genel olarak (%97.3) üreticilerin kendi arazileri üzerinde organik tarım yaptığı görülmektedir ve



birçoğu arazileri miras yoluyla (%93) edinmiştir. Türkiye’de tarımda tasarruf şekline bakıldığında kendi tarım arazisini işleyenlerin oranı ise %79.5’tir (KKB, 2020). Tarım alanlarının parçalı olması emek yoğun bir üretim şekli olan organik üretimde toprağın yönetimini zorlaştırmaktadır.

Yetiştirilen ürün sayısına bakıldığında genelde 1-2 ürünün yetiştirildiği (%62.6), 3-5 arası ürün yetiştirenlerin (%33) bu oranı takip ettiği görülmüştür. Çiftçilerin %84.3’ü tarım dışı gelire sahiptir. Üreticilerin %64.4’ünün ek gelir kaynağı emekli maaşıdır. Ankete katılan üreticilerin yaklaşık 1/3’ü sözleşmeli tarım yapmaktadır. Anket sonuçlarına göre üreticilerin büyük çoğunluğu, tüccara ya da sözleşmeli olarak fabrikaya satmaktadır. Kısa tedarik kanalları aracılığıyla ürünlerini pazara ulaştıran üretici sayısı ise sadece 4 kişidir. Anket yapılan üreticilerin %84,3’ünün kontrol-sertifika firmasının adını bilmediği tespit edilmiştir.

**Table 3. Characteristics of farms obtained from the questionnaire**

*Tablo 3. Anket çalışmasından elde edilen işletme özellikleri*

| Değişken                                     | Kategori                 | Frekans | %    |
|----------------------------------------------|--------------------------|---------|------|
| İşletme<br>Büyüklüğü(dekar)                  | 1-4                      | 2       | 1.7  |
|                                              | 5-9                      | 5       | 4.3  |
|                                              | 10-19                    | 13      | 11.3 |
|                                              | 20-49                    | 49      | 42.6 |
|                                              | 50-99                    | 28      | 24.3 |
|                                              | 100 üstü                 | 18      | 15.6 |
| Organik üretim<br>alanı büyüklüğü<br>(dekar) | 1-4                      | 11      | 9.6  |
|                                              | 5-9                      | 27      | 23.5 |
|                                              | 10-19                    | 29      | 25.2 |
|                                              | 20-49                    | 32      | 27.8 |
|                                              | 50-99                    | 10      | 8.7  |
|                                              | 100 üstü                 | 6       | 5.2  |
| Arazi mülkiyet<br>durumu                     | miras (mülk sahibi)      | 107     | 93   |
|                                              | satın alma (mülk sahibi) | 5       | 4.3  |
|                                              | kiracı                   | 1       | 0.9  |
|                                              | ortakçı                  | 1       | 0.9  |
|                                              | diğer                    | 1       | 0.9  |
| Arazi parçalılığı                            | evet                     | 96      | 83.5 |
|                                              | hayır                    | 17      | 14.8 |
|                                              | yanıtsız                 | 2       | 1.7  |

Üreticilerin organik tarıma devam etme eğilimleriyle sosyo-demografik özellikleri ve üretimin yapısı arasında ilişki karar ağacı modeli kullanılarak değerlendirilmiştir (Şekil 4). Bu değerlendirmede, organik tarıma devam etme eğilimi 115 üretici üzerinden incelenmiş ve 72 kişinin (%62.6) eğilimi yüksek çıkmıştır. 43 üretici ise (%37.4) düşük devam etme eğilimindedir. Algoritmanın bağımlı değişkeni açıklama düzeyi 0.322’dir (SE=0.044). Tablo 1’de ele alınan bağımsız değişkenlerden devamlılığı en fazla etkileyen faktörün yaş olduğu görülmektedir. Ortalama yaşın (57.5) altında olan üreticilerin devamlılık eğilimi (%76.5), ortalama yaş ve üzerinde olanlara göre (%51.6) daha yüksektir. Yaşı ortalamanın altında olan çiftçilerde de elde edilen gelire göre bir ayrışma olmaktadır. Yıllık organik tarımdan elde edilen geliri 50000 TL altında olan üreticilerde sözleşmeli tarım yapma, faaliyete devamlılığı artırıcı bir faktör olarak gözlemlenmiştir. Ortalamanın üzerinde yaşa sahip çiftçilerin sözleşmeli tarım yapanlarında devamlılık eğilimi yüksektir. Sözleşmeli tarım yapmayanlarda organik üretim deneyimi ortalamanın (12.5 sene) altında olan çiftçilerin destek almasının daha yüksek devam etme eğilimi sağladığı anlaşılmaktadır.

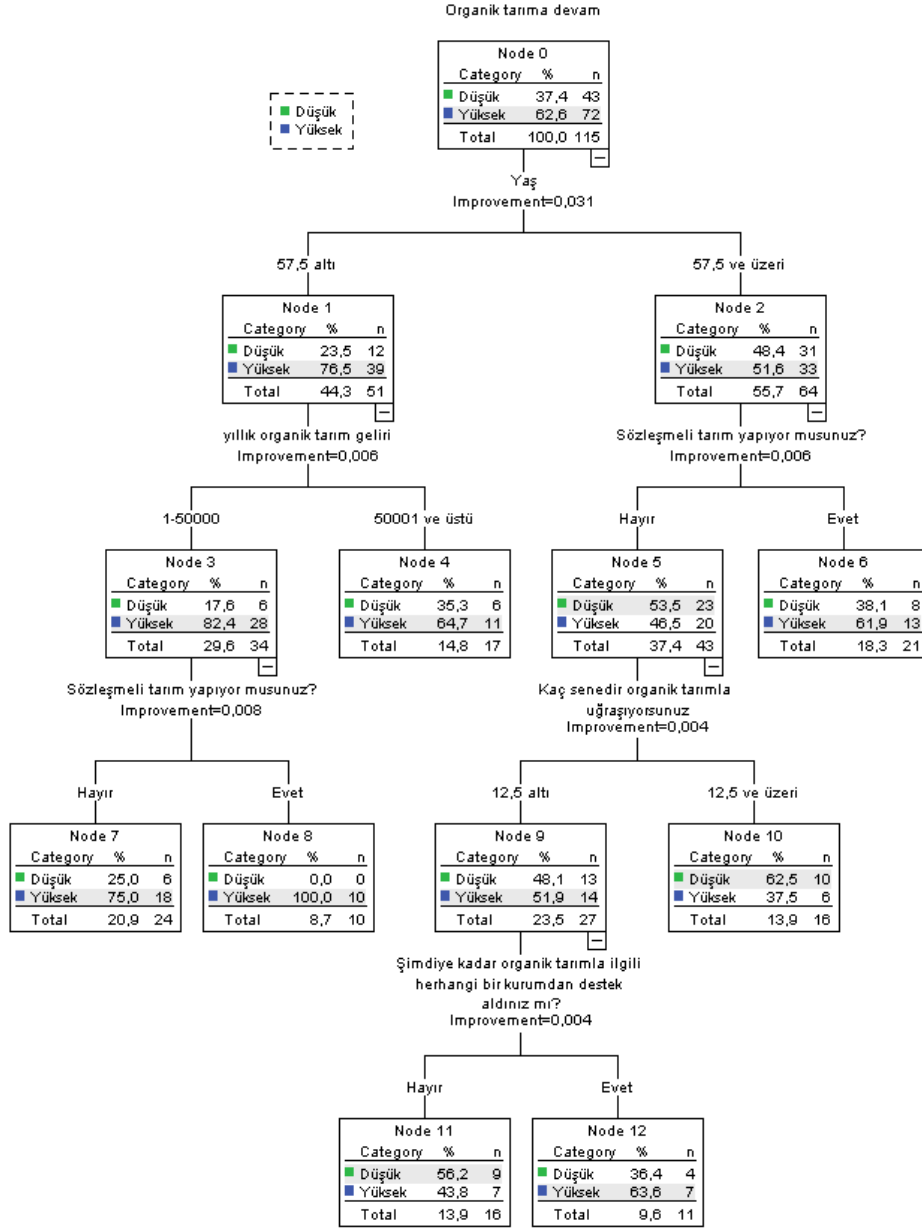


Figure 4. Tendency to continue organic farming CRT decision tree model

Şekil 4. Organik tarıma devam etme eğilimi CRT karar ağacı modeli

## 5. Tartışma ve Sonuç

Bu çalışma kapsamında, metropoliten alanların çevreinde organik tarım faaliyetinin devamlılığını etkileyen mekansal ve yapısal özellikler Bursa ili örneği üzerinden sorgulanmıştır. İkincil verilere dayalı betimleyici mekânsal analizler üzerinden 2021 yılı kesitine bakıldığında, organik tarım yapan işletmelerin dağınık bir şekilde yüksek rakımlı arazilerde yer seçtiği görülmüştür. Bursa'nın güney doğusunda dağ yöresi olarak adlandırılan bölgede, yoğun olmamakla birlikte bir yığılmanın varlığı söz konusudur. Konvansiyonel tarım ağırlıklı gelişme yörüngesi, ilde organik tarımın yer seçimini zorlaştırmakta ve dağınık yer seçimine sebep olmaktadır.

Bursa'da geleneksel tarım deneyimi ve bilgi birikiminin varlığı organik tarımın gelişmesi için fırsat sunmaktadır. Ancak nüfusun yaşlı olması, elde edilen gelirin ve eğitim düzeyinin düşük olması sebebiyle sosyo-ekonomik açıdan kırılgan bir yapıdan söz edilebilir. Yazındaki tespitlere benzer şekilde (Matysiak, 2021; Brodziak, 2017; Zuba-Ciszewska ve ark., 2023) Bursa'da organik üretime devam etme eğilimini en çok etkileyen faktör yaştır. Bursa'da genç çiftçi oranı (40 yaş altı; %7) düşüktür. Ortalamanın altında yaşa sahip üreticilerin devamlılığını etkileyen faktör

ise gelirdir. Sahm ve ark. (2013), mevcut araştırmalar üzerinden organik tarımın bırakılma sebeplerini inceledikleri çalışmalarında en belirleyici etmenin ekonomik koşullar olduğunu ifade etmektedir. İlgili yazıda, gelirin yanı sıra devlet desteğinin düşüklüğü de organik tarımın bırakılmasında önemli bir etmen olarak vurgulanmıştır. Bursa'da da benzer sonuçlar gözlenmektedir. İlde, kurumların sunduğu destekler ortalama yaşın üzerinde ve organik üretim deneyimi az olan üreticilerin devamlılığını olumlu etkilemektedir. Öyle ki anket sonuçlarına göre üreticilerin 4/5'i kurum destekleriyle organik tarımı devam ettirebileceğini belirtmiştir.

Bursa'daki işletmelerin büyük çoğunluğu küçük ölçekli, parçalı arazilere sahip, tek ürüne dayalı üretim yapan işletmelerdir. Sonuçta işletme büyüklüğü, arazi parçalılığı, üretimde çeşitlilik faktörlerinin organik tarım faaliyetlerine devam etmede etkisi tespit edilememiştir. Fakat büyük ölçekli tarım işletmeleri de oldukça azdır. Büyük tarım işletmeleri, ölçek ekonomisi etkisiyle daha verimli üretim yapabilmekte ve daha geniş pazar olanaklarına erişebilmektedir. Bu işletmelerin, üretim ve üretim sonrası aşamaları kendi organize etme ve sürdürme becerileri de bulunmaktadır. Fakat, yazında işletme ölçeği büyüdükçe organik üretimde ekolojik yaklaşımların yerini, verimlilik odaklı konvansiyonel pratiklere bıraktığı iddiaları da yer almaktadır (Liebert ve ark., 2022).

Satış kanalları açısından değerlendirildiğinde, küçük ölçekli işletmelerin (%73), ürettikleri ürünleri, tüccarlara ve ihracat yapan fabrikalara sözleşmeli olarak sattığı anlaşılmaktadır. Fabrikalar, çiftçilerin girdi tedarikinde ve sertifikasyon süreçlerinde yükünü üstlenmektedir. Karar ağacı modeline göre yaşı ortalamanın üstünde ve gelir düzeyi ortalamanın altında olan üreticilerin organik tarıma devam etmelerinde sözleşmeli tarım yapmak olumlu şekilde etkili olmaktadır. Aksi takdirde üretici organik üretimdeki girdi maliyetlerini karşılayamayarak sistemin dışına çıkmayı tercih etmektedir. Yazında da alım garantili üretimin sektörün devamlılığında etkili olduğu belirtilmektedir (Zuba-Ciszewska ve ark., 2023). Fakat dışa bağımlı olarak sadece yetiştiricilik faaliyetiyle ilgilenerek, sertifikasyon süreçleri, girdi ve pazarlama becerileri gibi konularda yeterli becerilerin kazanılamaması, katma değeri yüksek bir organik tarım faaliyetinin gelişmesini zorlaştırabilir. Doğrudan satış kanallarına dahil olamayan sözleşmeli tarım yapan çiftçilerin geçim koşullarının, kazancın adil paylaşımı ve organik tarım faaliyetlerinin sürdürülebilirliği açısından da sorgulanması gerekir. Bu bağlamda, kısa gıda tedarik zincirleri tarımın sürdürülebilirliğinde önemlidir. İlde, ürünlerini doğrudan tüketiciye ulaştıran sadece 4 üretici bulunmaktadır. İlde yüz yüze aracısız satış yapma imkanı sunan mekansal düzenlemenin sadece Nilüfer'de hizmet veren organik üretici pazarı olduğu görülmektedir. Ancak bölgedeki üreticilerin yereldeki tüketim piyasasıyla buluşması için maddi kapasitesinin düşük olduğu izlenmiştir. Nitekim Azima ve Mundler (2022), Kanada'da 613 çiftçi ile gerçekleştirdikleri araştırmada stres, çalışma yükü ve rekabete rağmen, doğrudan satış yapmanın ekonomik gelir ve iş tatminine olumlu katkı sağladığını tespit etmişlerdir. Dolayısıyla Bursa'da özellikle küçük ölçekli işletmelerin bu yöndeki bilgi ve becerilerini geliştirecek desteklere ihtiyacı vardır. Diğer taraftan yerel gıda sistemleri ve organik tarım ilişkisinin güçlendirilmesi kentlerin gıda güvenliğini artırmada önemli olacaktır. Yereldeki tüketim piyasasıyla üretim piyasasını buluşturan mekanizmalara kentsel politikalarda yer verilmelidir.

Yazında, küçük ölçekli tarım işletmelerinin üretime devam etmesini ve refah düzeyinin yükselmesini sağlayacak destek sistemlerinden birinin de kooperatiflere üyelik olduğu ifade edilmektedir. Çiftçiler arası sivil dayanışma yenilikçi pratiklerin benimsenmesine katkı sağlamaktadır (Kumar ve ark., 2018; Candemir ve ark., 2021; Yu ve ark., 2021; Ma ve ark., 2018). Bursa özelinde dernek-kooperatif üyeliği organik tarıma devam etme eğiliminde etkili gözükmemektedir. Önceden değinildiği üzere üreticilerin %86.1'i Ziraat Odası, Köy Kalkınma Kooperatifi ve İlçe Tarım Kredi Kooperatifi'ne üyedir. Ancak ilde organik tarıma özgü bir oluşum ve örgütlenme bulunmamaktadır. Bu durum organik tarımın devamlılığını sağlamada bir eksiklik olarak değerlendirilebilir. Organik tarım faaliyetinde sivil dayanışmanın sağlanması, üreticinin birçok sorunla tek başına mücadele etmesinin önüne geçerek üretim pratiğinin devamlılığını destekleyebilir. Organik tarımda, bilgi yoğun üretim tekniklerini içermesi sebebiyle yeni yöntemlerin öğrenilmesi ve karşılaşılan zorluklarla mücadelede kamu kurumlarının desteğinin yanı sıra diğer çiftçilerle dayanışma ve işbirliği değerlidir.

Sonuç olarak, Türkiye'de büyük kentlerde sürdürülebilir tarım olanaklarının daha kapsamlı bir şekilde analiz edilmesi, bu analizlerin üst ve alt ölçekte gelişme politikalarına yön veren stratejik belgelerde yer bulması gerekmektedir. Planlama süreçlerinde tarım üretimini teşvik edecek ve koruyacak mekânsal kararların üretilmesi önem arz etmektedir. Araştırma, Bursa özelinde organik tarıma ilişkin betimleyici mekânsal bulgular sunmuş ve çiftçilerin devam etme eğilimlerini üretici ve üretim yapısı üzerinden incelemiştir. Fakat organik tarıma devam etme eğiliminde; mekanda bir arada olma ve kümelenme etkisi daha kapsamlı ele alınması gereken bir konudur. Yazında, üretici ve üretimin yapısal özelliklerinin organik tarım pratiğine devam etme üzerindeki yansımalarını inceleyen kısıtlı sayıda

çalışma bulunmaktadır. Araştırmaların daha çok konvansiyonel üretimden organik tarıma geçiş süreçlerini ele aldığı görülmüştür. Çalışmada, yazından farklı olarak işletmelerin birçoğunun küçük ölçekli ve parçalı arazilere sahip olması nedeniyle, bu unsurların çiftçilerin üretime devam etme eğiliminde etkisi görülememiştir. Ürün çeşitliliği işletmelerin dayanıklılığını artıran bir unsur olmakla birlikte, bu araştırmada yine organik tarım pratiğinin sürdürülmesiyle ilişkisi tespit edilmemiştir. Elde edilen bulgulara yazından farklılaşmalar, mikro ölçekli yerel yaklaşımların değerli olduğunu ve bağlamın önemini ortaya koymaktadır. Bu araştırma, organik üretim pratiğinin yaygınlaştırılması ve devam etmesinde yere özgü niteliklerin de ele alınması gerektiğini vurgulamaktadır. Diğer taraftan, tarımsal üretimde farklı bir pratiğe geçişin ve yenilikçiliğin geliştirilmesi için süreçlere ilişkisel bakmak gerekmektedir. Mikro ölçekte üretim boyutu üzerinden değerlendirmelere dayalı olarak sürdürülebilir tarımın gelişmesini sağlamak yeterli olmayacaktır. Bundan dolayı yerel gıda zincirinin gelişmesi ve gıda güvenliğinin sağlanması için mezo ve makro ölçekte tüm aktörler arası ilişki ağlarını değerlendiren araştırmalar, uygulamaya yönelik politikaların üretilmesine önemli katkılar sağlayacaktır.

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Makale yazarları olarak aramızda herhangi bir çıkar çatışması olmadığını beyan ederiz.

### **Yazarlık Katkı Beyanı**

Planlama: Seçkin, E., Senem Kozaman, A.; Materyal ve Metot: Seçkin, E., Senem Kozaman, A.; Veri toplama ve İşleme: Seçkin, E., Senem Kozaman, A.; İstatistiki Analiz: Seçkin, E., Senem Kozaman, A.; Literatür Tarama: Seçkin, E., Senem Kozaman, A.; Makale Yazımı, İnceleme ve Düzenleme: Seçkin, E., Senem Kozaman, A.;

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**Projections of Agricultural Product Exports and Their Impacts on Rural Development**

Tarımsal Ürün İhracatının Projeksiyonları ve Kırsal Kalkınma Üzerindeki Etkileri

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Food security and sustainable development are among the critical issues of today. Addressing these challenges requires a focus on sectors that can simultaneously ensure food availability and foster sustainable progress. In this context, the agricultural sector serves as a driving force for both rural development and economic growth by enhancing productivity, promoting export-oriented strategies. This study examines Turkey's agricultural products' foreign trade situation, focusing on export-oriented development strategies. The research analyzes agricultural products' import and export data from the years between 2000 to 2023, obtained from the UN Comtrade database. The data consist of nine product groups within Chapters 06-14 of Section 2 of the Customs Tariff Schedule. Using statistical methods, including the Mann-Kendall and Sen's Slope Trend tests, the study investigates foreign trade trends and makes future projections. The results indicate that there is a general upward trend in exports. Export surpluses are expected in product groups such as live trees and other plants, vegetables, fruits, milling products, oilseeds, and vegetable materials for knitting. However, deficits persist in groups such as tea, coffee, spices, cereals, and lacquers, gums, and resins, where imports exceed exports. The most important export product group with the highest surplus is fruit, whereas the highest deficit ratio is observed in cereals. Based on the result of analysis, increasing Turkey's agricultural export performance holds strategic importance for rural development and economic growth. Therefore, reducing import dependency and promoting domestic production are essential for sustainable development in the agricultural sector. Additionally, supporting product groups with competitive advantages in agricultural exports and expanding their market share are recommended. The adoption of modern agricultural techniques, the training of farmers, and the development of rural infrastructure will also contribute to the sustainable growth of the sector and, in turn, support rural development. Structural transformation policies and improvements in the agricultural sector will contribute significantly to strengthening local economies and ensuring national economic stability by encouraging rural development.

**Keywords:** Rural development, Agricultural export, Mann-Kendall, Sen's Slope Trend tests, Future projections

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## Öz

Gıda güvenliği ve sürdürülebilir kalkınma, günümüzde kritik konular arasında yer almaktadır. Bu zorlukların ele alınması gıda güvenliğini ve sürdürülebilir kalkınmayı sağlayacak sektörlerle odaklanmayı gerektirmektedir. Bu bağlamda tarım sektörü, üretkenliğin artırılması ve ihracata yönelik stratejileri teşvik edilmesiyle hem kırsal kalkınmanın hem de ekonomik büyümenin sağlanmasında lokomotif görevi görmektedir. Bu çalışma, ihracata dayalı kalkınma stratejisi benimseyen bir ülke olarak Türkiye'nin tarımsal ürün gruplarına yönelik dış ticaret durumunu incelemektedir. Araştırma, BM Comtrade veri tabanından elde edilen 2000-2023 yıllarına ait tarım ürünleri ihracat ve ithalat verilerini analiz etmektedir. Veriler Gümrük Tarife Cetveli 2. Bölüm 06-14. Fasıllar arasında yer alan 9 ürün grubundan oluşmaktadır. Mann-Kendall ve Sen Trend testi gibi istatistiksel yöntemler kullanılarak yapılan analizlerde dış ticaret trenleri ve gelecekteki eğilimleri incelenmiştir. Sonuçlar, ihracatın genel olarak artış eğiliminde olduğunu göstermiştir. Canlı ağaçlar ve diğer bitkiler, sebzeler, meyveler, değirmencilik ürünleri, yağlı tohumlar ve örülmeye elverişli bitkiler ürün gruplarında ihracat fazlası oluşması beklenmektedir. Bununla birlikte ithalatın ihracatı aştığı; çay, kahve ve baharatlar, hububat ile sakız, reçine hülasalar ürün gruplarında cari açık oluşacağı beklenmektedir. En yüksek ihracat fazlasının oluştuğu ürün grubu meyveler olurken, en yüksek cari açık oranı da tahıllarda gözlenmiştir. Analiz sonuçlarına göre Türkiye'nin tarımsal ihracat performansının artırılması, kırsal kalkınma ve ekonomik büyüme açısından stratejik bir öneme sahiptir. Bu sebeple, tarım sektöründe sürdürülebilir kalkınmanın sağlanabilmesi için ithal bağımlılığın azaltılması ve yerli üretimin teşvik edilmesi gerekmektedir. Ayrıca, tarımsal ürün ihracatında rekabet avantajı bulunan ürün gruplarının desteklenmesi ve bu ürünlerin pazar payının artırılması önerilmektedir. Modern tarım tekniklerinin benimsenmesi, çiftçilerin eğitimi ve kırsal altyapının geliştirilmesi de sektörün sürdürülebilir büyümesine ve bu sayede kırsal kalkınmaya katkı sağlayacaktır. Yapısal dönüşüm politikaları ve tarım sektöründeki iyileştirmeler, kırsal kalkınmayı teşvik ederek yerel ekonomilerin güçlenmesine ve ulusal ekonomik istikrarın sağlanmasına önemli katkılarda bulunacaktır.

**Anahtar Kelimeler:** Kırsal kalkınma, Tarımsal ihracat, Mann-Kendall, Sen's Slope Trend testi, Gelecek projeksiyonları

## 1. Introduction

Population growth and global climate change pose various problems in many sectors, especially in agriculture and food sectors. Reports from reputable international organizations indicate that the world may soon face significant challenges in providing sufficient food for its growing population. This potential shortfall could lead to a cascade of economic, social, and political issues. Especially in Türkiye, these challenges are expected to be even more pronounced compared to similar countries due to several factors such as the country has one of the highest population growth rates globally and also hosts the largest refugee population in the world. Moreover, Türkiye's agricultural sector has been struggling with a sharp decline in recent years, leading to an increasing reliance on imported food and agricultural products (Açıkgöz, 2023). This situation can be even more challenging for people in underdeveloped rural areas. In addition to economic concerns, people living in areas where natural resources cannot be used efficiently face many social problems such as poverty and inequality, inadequate health services. Because of with these difficulties hunger being one of the most critical global issues in future that highlights the importance of food security and sustainability (Yıldırım and Kaplan, 2022). Accordingly, the concept of rural development, one of the most critical elements of sustainable development, has become an important topic of discussion in recent years.

While rural development is the subject of academic study in different disciplines, in practice, it is both researched by international organizations such as Organisation for Economic Co-operation and Development (OECD) and Food and Agriculture Organization (FAO), and is also the focus of projects led by international financial institutions like the World Bank (Elibol, 2019; Anonymous, 2021a; Anonymous, 2022a; Anonymous, 2024a; Anonymous, 2024b). Rural development essentially refers to the totality of activities and actions of various actors that lead to progress in rural areas. There are various definitions of the concept in the literature. According to the United Nations (UN) definition of the Second Decade of Development, "rural development refers to the fundamental transformation of social and economic structures, institutions, relationships and processes in any rural area". This implies that rural development aims for not only agricultural and economic growth, but also balanced social and economic progress. Its aim is to transform rural society and provide a better and safer life for the people (Oakley and Garforth, 1985).

The development of rural areas is important not only to increase agricultural productivity, but also to strengthen the social fabric of local communities and diversify economic opportunities. Agriculture, in particular, is the main source of foreign exchange inflows for a country on the road to industrialization. However, many developed countries have completed their development by increasing productivity in agriculture and transferring the funds created in this sector to non-agricultural resources (Seyidoğlu, 2017).

Historically, the concept of development has generally been associated with material progress. In other words, it focuses on increasing income and wealth and reducing poverty. However, over time, the understanding of development has evolved beyond material aspects. This approach is now rooted in a more holistic foundation, incorporating cultural, spiritual, and ethical values. This shift is also evident in the agricultural sector, a key component of rural development, which has been supported by the transition to sustainable agriculture (Shepherd, 1998).

When analyzing agricultural production in Turkey, it is evident that production increased significantly starting in the 1930s, especially after World War II, due to the cultivation of new lands. However, by the late 1960s, the limit of arable land had been reached. Although the country remained self-sufficient in agriculture despite rapid population growth during this period, after the 1960s, agricultural production growth could only be achieved through enhanced soil fertility. In 1963, with the introduction of the first five-year development plan, Turkey implemented planned rural development programs, projects, and support initiatives. This plan emphasized that the country's general exports would heavily rely on agricultural products (Anonymous, 1963). Until the late 1970s, the rate of agricultural production growth exceeded population growth, but this trend could not be sustained in subsequent years (Pamuk, 2018). The 1980s marked a pivotal period in Turkey when export-oriented industrialization took precedence, following the economic reforms of January 24. During this time, policies such as trade liberalization, export incentives, and increased foreign capital inflows were introduced. Unlike import substitution strategies, the focus shifted to supporting industries with the potential to grow and compete internationally (Seyidoğlu, 2017). As a result, this era also initiated an export-oriented transformation in Turkey's

agricultural sector. Export-driven growth has been recognized as a crucial strategy for economic development, particularly in rural areas. Agricultural development in a country is closely linked to the advancement of its rural regions. In recent years, efforts to tackle existing challenges have heightened the emphasis on promoting agricultural development and entrepreneurship in Turkey (Sarı Gedik and Yılmaz, 2023).

Turkey's agricultural sector has also gained significant importance in line with global trends (Anonymous, 2021b). The agricultural sector is crucial for economic growth and food security, and it remains vital for Turkey in terms of both employment and exports. However, an examination of the sector's foreign trade balance reveals ongoing challenges. As of November 2024, agriculture accounted for only 3.6% of Turkey's total exports, and the sector faced a trade deficit of \$1.525 billion (Anonymous, 2024c). These issues highlight the sector's foreign trade imbalances and the need for targeted strategies to address them.

When the academic literature is analyzed, it is seen that rural development is addressed in many dimensions in different disciplines. While Amao et al. (2021) investigate the impact of agricultural exports on economic development, Nagy et al. (2022) emphasize that interventions based on research and technologies to increase agricultural productivity have a critical role in ensuring food security and supporting rural development. However, they also stated that sustainable development cannot be achieved unless the improvement in agricultural productivity is supported by foreign trade (Nagy et al., 2022). In addition, the export competitiveness of agricultural products in the perspective of rural development has also been mentioned as a noteworthy issue (Hu and Lin, 2024). These studies demonstrate that rural development and international trade are closely interlinked, particularly through the economic dimension. However, the number of empirical studies that directly examine the effect of agricultural exports on rural development remains limited. In this context, the present study aims to contribute to the literature by focusing on the economic relationship between agricultural exports and rural development in Turkey, a country that has adopted an export-oriented development strategy.

The aim of this study is to analyze Turkey's economic and rural development processes based on agricultural product exports, and to make an assessment for the next 15 years by calculating the trend of the trend between 2000 and 2023 based on the current situation. The study aims to draw attention to the importance of an export-based structural transformation in the agricultural sector and to reveal the potential effects of this transformation on rural development. Thus, the strategic role of Turkey's agricultural export performance in terms of both economic growth and sustainable development in rural areas will be emphasized.

The scope of this study is limited to the economic dimension of rural development, with a particular focus on crop-based product groups. The social, political, and institutional aspects of rural development have been deliberately excluded, as they fall outside the methodological framework of the study. In this context, the export-oriented structural transformation in the agricultural sector and its economic impacts on rural areas are examined within the framework of the international trade discipline.

## 2. Materials and Methods

The main material of the research consists of secondary data obtained from the UN Comtrade database (Anonymous, 2024d.). In this context, data on Chapters 06-14 of Section 2 of the Customs Tariff Schedule were collected. In the study, non-parametric Mann-Kendall trend test and Sen's Trend Tendency Estimator methods were used to reveal the trends and variations of import, export and foreign trade balance (current account deficit/surplus) data of 9 product groups on a total year basis between 2000-2023. After determining the appropriate models in this process, the annual import, export and foreign trade balance values of 9 product groups between Chapters 06-14 until 2038 were predicted. The time series of the data were meticulously evaluated using software such as RStudio, Minitab and Microsoft Office Excel. Information on the chapters within the scope of plant products is given in *Table 1*.

### 2.1. Methods used in Trend Analysis

In time series, the change of parameter values in the direction of increase or decrease is called trend. Trend analyses are models that show the change in the increasing or decreasing trends of the variable of interest over time during the period of observation. The main purpose of trend analysis in time series analysis is to predict future trends based on past data. In addition, in recent years, it has become an important tool in forecasting the future.

The only difference from the simple linear regression model is that the independent variable is time. With these analyzes, it is important to understand the future trends and make strategic decisions by determining whether the relevant products have a trend in the specified time interval.

**Table 1. Section 2 of the Customs Tariff Schedule, Chapters and Descriptions of Vegetable Products**

| Chapter No | Product Description                                                                                                |
|------------|--------------------------------------------------------------------------------------------------------------------|
| 06         | Live Trees and Other Plants; Tubers, Roots and the Like; Cut Flowers and Ornamental Foliage                        |
| 07         | Edible Vegetables and Some Roots and Tubers                                                                        |
| 08         | Edible Fruits and Edible Hard-Shelled Fruits; Citrus and Melon and Watermelon Rinds                                |
| 09         | Coffee, Tea, Paraguayan Tea and Spices                                                                             |
| 10         | Grain                                                                                                              |
| 11         | Milling Products; Malt; Starch; Inulin; Wheat Gluten                                                               |
| 12         | Oil Seeds and Fruits; Miscellaneous Grains, Seeds and Fruits; Plants Used in Industry and Medicine; Hay and Forage |
| 13         | Lacquer; Gum, Resin and Other Vegetable Extracts and Extracts                                                      |
| 14         | Vegetable Materials Suitable for Knitting; Vegetable Products Not Elsewhere Specified or Included in the Tariff    |

### 2.1.1. Least Squares Method (LSM)

The trend of the import and export value of the products included in the scope of the study over the years is calculated by the Least Squares Method (LSM). For the application of the LSM, a time series graph must first be drawn. The most appropriate function type was determined according to the development trend of this graph (Serper, 2004). Some trend models used in LSM are the linear and quadratic models in equations 1 and 2.

- Linear regression model,

$$Y_i = b_0 + b_1X_i + \varepsilon_i, i = 1, 2, \dots, n \text{ (Gujarati, 2003).} \quad (\text{Eq.1})$$

- Quadratic regression model,

$$Y_i = b_0 + b_1X + b_2X^2 + \varepsilon_i, i = 1, 2, \dots, n \text{ (Akkaya, 1990).} \quad (\text{Eq.2})$$

### 2.1.2. Mann Kendal (MK) Test

The test developed by Mann-Kendal is one of the widely used methods for trend analysis in time series. The Mann-Kendall test is widely used because it has many advantages such as not requiring the data to fit a particular distribution and can be applied in case of missing data. It is a particularly effective tool for detecting non-linear trends and helps to identify long-term trends in commercial data with seasonal fluctuations. The Mann-Kendall test is based on the calculation of the correlation coefficient. The  $n$  elements in the data set are arranged in  $(n_1, n_2, \dots, n_m)$  time order and each  $X_n$  value is used as a benchmark. Each  $n = 1, 2, \dots, m - 1$  value for  $X_m$  from the start of the measurement to the end date is compared with the  $j = n + 1, n + 2, \dots, m$  values in the interval  $X_j$ . MK test statistic  $S$  is as in Equation 3;

$$S = \sum_{n=1}^{m-1} \sum_{j=n+1}^m \text{Sgn}(X_j - X_n) \quad (\text{Eq.3})$$

Where  $X_j$  and  $X_n$  denote the data in years  $j$  and  $n$ . If  $j > n$ , The sign function (Sgn) is expressed in the equation in Equation 4:

$$\text{Sgn} = (X_j - X_n) = \begin{cases} (X_j - X_n) > 0 & \text{if } +1 \\ (X_j - X_n) = 0 & \text{if } 0 \\ (X_j - X_n) < 0 & \text{if } -1 \end{cases} \quad (\text{Eq.4})$$

In the variance calculation of the MK test statistic  $S$ ,  $m$  denotes the number of years in the series. After the variance is calculated, whether the test is significant at the specified significance level is determined by comparing



it with the critical Z value given in the equation below. The Critical Z value in Equation 6 is the standard normal distribution.

$$Var(S) = \frac{m(m-1)(2m+5)}{18} \quad (\text{Eq.5})$$

$$Z = \begin{cases} S > 0 & \text{if } S - \frac{1}{\sqrt{Var(S)}} \\ S = 0 & \text{if } 0 \\ S < 0 & \text{if } S + \frac{1}{\sqrt{Var(S)}} \end{cases} \quad (\text{Eq.6})$$

If the absolute value of the Z value is less than its value in the normal distribution according to the significance level, the null hypothesis is accepted. In this case, it is concluded that the analyzed time series does not contain a trend. However, if the Z value is high, a trend is considered to be present. If the Z value is positive, this indicates an upward trend; if it is negative, it is said to be a downward trend (Yue et al., 2002).

### 2.1.3. Sen's Slope Test

This test statistic, defined by Hirsch et al., (1982), is a nonparametric trend test developed by Sen (1968). In the Sen trend test, the amount of change in a slope in the series per unit time is determined. Errors and extreme values of the data used in the test do not affect the results, so the test can be applied even if there are deficiencies in the series (Bacanlı and Çukurluoğlu, 2018). According to this test, the values of times j and k in the data set sorted as  $(n_1, n_2, \dots, n_m)$ ;  $X_j$  and  $X_n$  denote the data in years j and n. Thus, If  $j > n$  is,  $N = n(n+1)/2$ ,  $Q_i$ , the value of  $n = (1, 2, \dots, N)$  It is calculated as in Equation 7;

$$Q_i = \frac{X_j - X_k}{j - k} \quad (\text{Eq.7})$$

is obtained with the formula. The resulting  $Q_i$  values are ordered from smallest to largest. The median of these  $N$ ,  $Q_i$  values is an appropriate statistic to estimate the linear trend slope parameter. However, here the median value is determined by different calculations, such as in Equations 8 and 9, depending on whether N is odd or even. If N is odd;

$$Q_{\text{median}} = Q_{(N+1)/2} \quad (\text{Eq.8})$$

If N is even;

$$Q_{\text{median}} = (Q_{N/2} + Q_{(N+1)/2})/2 \quad (\text{Eq.9})$$

A negative median value indicates a decreasing trend, while a positive median value indicates an increasing trend. The calculated median value of Q is evaluated with a two-way test with a 95% confidence interval using Sen's nonparametric method, and thus a judgment is made about the true slope (Bai et al., 2014).

## 3. Results and Discussion

The Mann-Kendall and Sen test results of the import and export data of 9 product groups for the period 2000-2023 are given in Table 2 and 3. According to the Mann-Kendall test results,  $H_0$  (no trend) hypothesis was evaluated at two-way 95% ( $z=1.96$ ) and 90% ( $z=1.645$ ) confidence intervals. Table 2 and 3 show that there is an increasing trend ( $p<0.05$ ) in the exports and imports of product groups for the years 2000-2023, and according to the Sen' Slope test result, the slope is positive.

The export perspectives and projections for 9 different product groups in the plant products group for the period 2000-2038 are given in (Figure 1). Accordingly, the most prominent product group in exports is Chapter 8 fruits.

The visualization of import perspectives and projections prepared for 9 different product groups in the crop products group for the period 2000-2038 is given in (Figure 2). Accordingly, the most prominent product group in exports is Chapter 10 cereals.

**Table 2. Mann-Kendall and Sen Test Results for Annual Export Data**

| Chapter | MK Test | P value | Sen's Slope |
|---------|---------|---------|-------------|
| 06      | 6.325,1 | 0.0000  | 5.055,107   |
| 07      | 5.481,8 | 0.0000  | 6.8530,65   |
| 08      | 6.027,5 | 0.0000  | 1.884,448   |
| 09      | 6.077,1 | 0.0000  | 1.0438,14   |
| 10      | 2.505,2 | 0.0122  | 1.1830,20   |
| 11      | 6.176,3 | 0.0000  | 7.5742,24   |
| 12      | 6.176,3 | 0.0000  | 2.3511,97   |
| 13      | 5.729,8 | 0.0000  | 869.566,7   |

**Table 3. Mann-Kendall and Sen Test Results for Annual Import Data**

| Chapter | MK Test | P value | Sen's Slope |
|---------|---------|---------|-------------|
| 06      | 3.050,9 | 0.0022  | 2.672,329   |
| 07      | 5.1841  | 0.0000  | 3.531,808   |
| 08      | 6.0771  | 0.0000  | 4.492,372   |
| 09      | 6.4739  | 0.0000  | 1.864,608   |
| 10      | 4.8865  | 0.0000  | 1.743,250   |
| 11      | 6.4243  | 0.0000  | 8.765,130   |
| 12      | 6.1763  | 0.0000  | 1.177,817   |
| 13      | 5.0849  | 0.0000  | 2.123,753   |

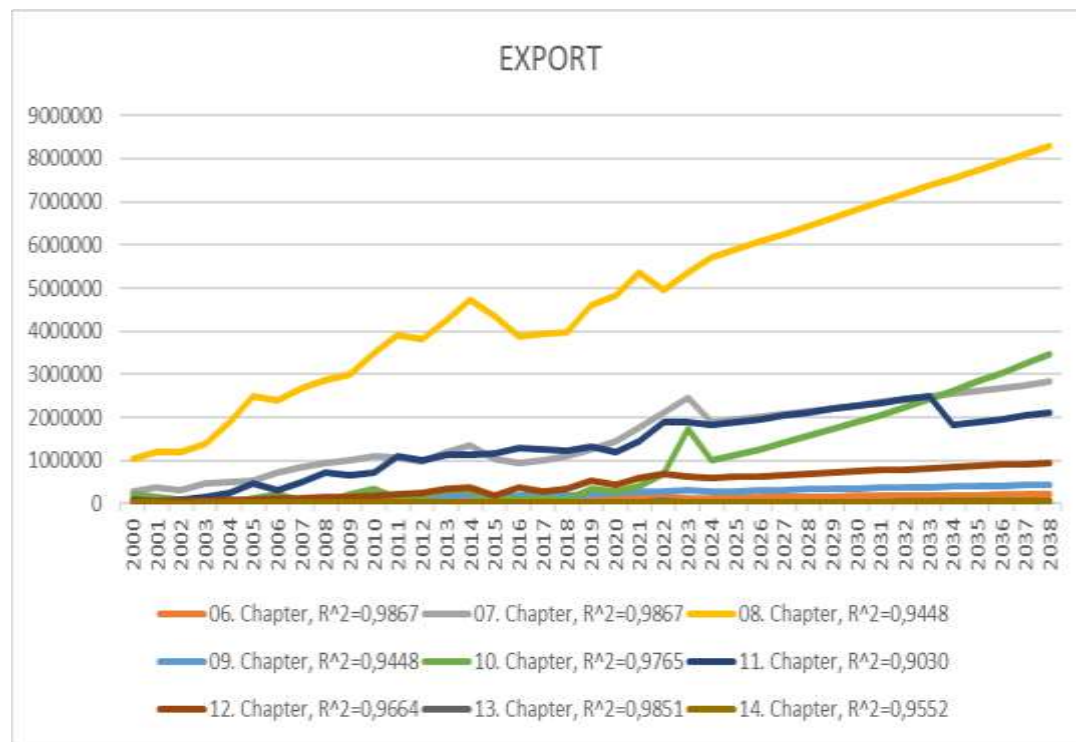


**Figure 1: Crop Export Perspectives and Projections between 2000 and 2038**

Future projections for the chapters in Turkey's Customs Tariff Schedule, Section 2, Agricultural products group are given in Table 4. According to the results of the analysis; in Chapter 6, it is projected that there will be a current account surplus as a result of an increase in export value by 56.13% to \$211.140 and import value by 60.06% to \$110.204 in 2038. In Chapter 7, it is projected that there will be a current account surplus as a result of an increase in export value by 15.44% to \$2.823.613 and import value by 13.44% to \$1.436.392 in 2038. In Chapter 8, it is projected that there will be a current account surplus in 2038 as a result of an increase in the value of exports by 54.43% to \$8.290.249 and an increase in the value of imports by 37.83% to \$1.740.756. In Chapter 9, a current

account deficit is projected to emerge in 2038 as a result of a 15.44% increase in the value of exports to \$2.823.613 and a 21.65% increase in the value of imports to \$754.571. In Chapter 10, a current account deficit is projected to emerge as a result of an increase of 100.93% in the value of exports to \$3.481.170 and an increase of 33.17% in the value of imports to \$6.758.872 in 2038. In Chapter 11, a current account surplus is projected to emerge as a result of an increase in the value of exports by 52.99% to \$2.870.258 and an increase in the value of imports by 42.26% to \$347.814 in 2038. In Chapter 12, the current account surplus is projected to be realized as a result of an increase of 48.71% in the value of exports to \$951.333 and 56.99% in the value of imports to \$469.413 in 2038. In Chapter 13, a current account deficit is projected to emerge as a result of an increase of 187.69% in the value of exports to \$46.593 and an increase of 23.59% in the value of imports to \$100.426 in 2038. In Chapter 14, a current account surplus is projected to emerge as a result of an increase in the value of exports by 63.97% to \$55.675 and an increase in the value of imports by 68.62% to \$25.195 in 2038.

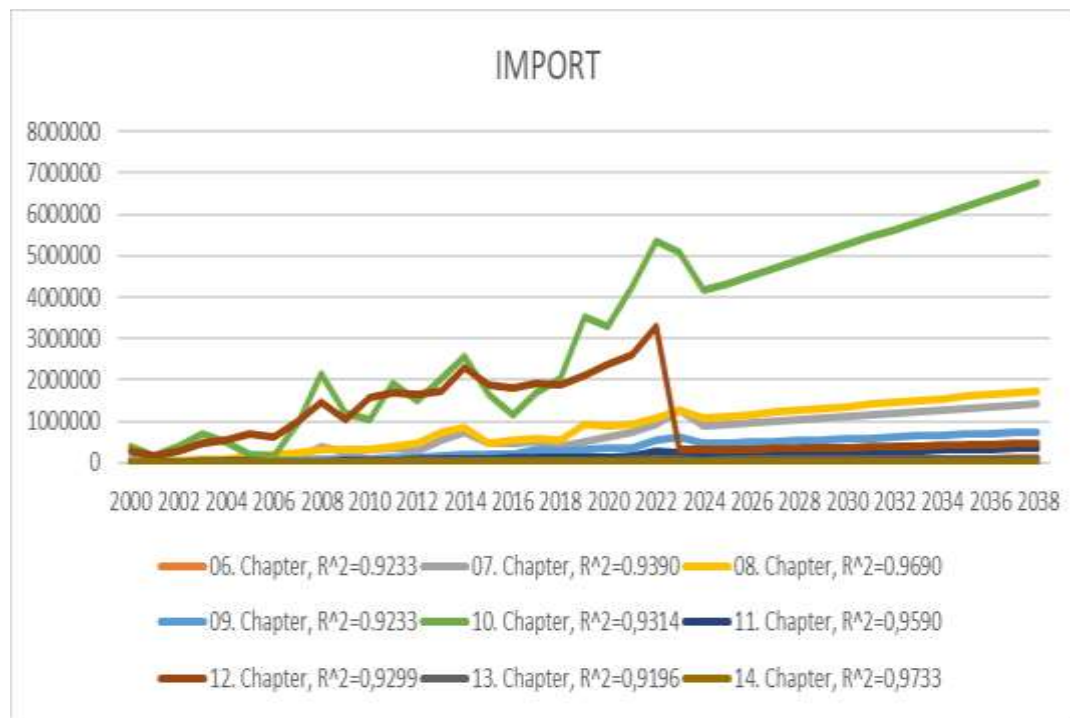


**Figure 2: Crop Products Import Perspectives and Projections between 2000 and 2038**

These projections reveal how the trade flows of Turkey's agricultural product groups are shaping and indicate the emergence of current account surpluses and deficits in different chapters. It is considered that Turkey's future agricultural trade performance will be influenced not only by trade flows or market conditions but also by structural factors such as rural economic development. Although these issues were already highlighted more than two decades ago, they continue to persist, particularly in key agricultural product groups. Similar concerns about Turkey's long-term dependency on agricultural imports were also identified in the study conducted by Koç et al. (2001) under the Agricultural Economics Research Institute. In their projections Turkey will continue to be a net importer of many products, particularly beef, lamb, cotton, corn, soybean, sunflower, and rice, and by the end of the ten-year period (till 2010), wheat and sugar will also be added to this list. The study highlighted that Turkey would become increasingly dependent on agricultural and food imports, unless structural measures such as the use of high-yield seeds, increasing productivity in meat and dairy production, and reducing feed costs in livestock farming are implemented. When considered together with current projections, these earlier findings underline that the need for rural economic development and structural transformation in agriculture remains critical to ensure sustainable agricultural trade performance.

Moreover, as of 2023, these concerns largely remain valid, and it is evident that Turkey's agricultural sector still faces significant structural problems, particularly in Chapter 9 (Coffee, Tea, and Spices), Chapter 10 (Cereals), and Chapter 13 (Lac; Gums, Resins, and Other Vegetable Saps and Extracts) product groups. Despite some efforts toward production planning and support mechanisms, a high dependency on imports continues, especially in the

cereals group. Along with the current economic conditions and a high inflation environment, the high costs of essential agricultural inputs remain one of the most pressing problems for producers. This situation significantly reduces the competitiveness of domestic producers both in domestic and international markets. Additionally, other major issues in the sector include the insufficient dissemination of high-yield seeds and modern agricultural technologies, fragmented and small-scale agricultural lands that prevent achieving economies of scale, and the negative impacts of climate change such as drought and water scarcity.

Furthermore, another recent scientific study conducted by Çiftçi (2024) provides more concrete and data-driven findings regarding the future of Turkey's cereal production, clearly revealing the structural problems faced by the sector. In this context, the study focuses on wheat and barley, which are among the most produced grains worldwide and play a significant role in both human and animal nutrition, thereby forming the foundation for ensuring sustainable food security. By employing Artificial Neural Networks (ANN) and Linear Regression techniques, the study presents projections for Turkey's production, import, export, and population trends between 2023 and 2032. According to ANN-based projections, Turkey's wheat production is expected to reach approximately 22.96 million tons by 2032. Additionally, the production area is projected to increase to 7.55 million decares, wheat exports are expected to reach 1.08 million tons, while imports are anticipated to remain at a high level of approximately 13.7 million tons. Regarding barley, production is expected to rise to 9.19 million tons by 2032, and the production area is projected to expand by 8%, reaching 3.48 million decares. However, barley imports are estimated at around 1.81 million tons, and exports are projected to be 398,489 tons. These findings demonstrate that although there is a moderate increasing trend in production, import dependency for both wheat and barley will persist, which will continue to be a fundamental issue for Turkey's food security and foreign trade balance. It appears unlikely that Turkey will achieve self-sufficiency in the cereal sector without structural reforms and targeted rural development policies.

The research particularly emphasizes the necessity of utilizing data-driven forecasting models, such as Artificial Neural Networks (ANN), in agricultural production planning. By doing so, it is argued that strategic decision-making processes can be improved, supply security risks can be mitigated, and resilience against climate and market fluctuations can be strengthened.

While such long-term, data-driven planning is systematically carried out by developed countries, such as in the United States Department of Agriculture (USDA) Agricultural Projections to 2034, where detailed, data-driven scenarios for agricultural production, trade, and market evolution are used to guide policymaking and ensure food security (Dohlman, et. al., 2025). However, similar long-term strategic planning tools are still limited in Turkey, making it crucial to integrate such forward-looking perspectives into rural development and agricultural transformation policies.

Considering similar studies in the literature and the findings of this research, it is concluded that analyzing trade flows alone is insufficient, and Turkey must implement comprehensive rural development and agricultural transformation policies. These policies should aim to increase agricultural productivity, ensure food security, and reduce import dependency through sustainable and data-based strategies. As Hu and Lin (2024)'s findings confirm that rural economic development significantly enhances the export competitiveness of agricultural products, with this effect being more pronounced in developed regions. Their study highlights that rural economic development has a positive impact on the export competitiveness of agricultural products through rural human capital accumulation. This situation could be a determining factor in sustaining Turkey's agricultural trade balance in the long term and ensuring rural development.

1 *Table 4. Foreign Trade Projections by Chapters*

| Products / Years       |                         | 2023      | 2024      | 2025      | 2026      | 2027      | 2028      | 2029      | 2030      | 2031      | 2032      | 2033      | 2034      | 2035      | 2036      | 2037      | 2038      |
|------------------------|-------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 06. Chapter<br>x1000\$ | Export                  | 135.226   | 136.646   | 141.967   | 147.288   | 152.609   | 157.930   | 163.251   | 168.572   | 173.893   | 179.214   | 184.535   | 189.856   | 195.177   | 200.498   | 205.819   | 211.140   |
|                        | Import                  | 67.581    | 79.390    | 81.591    | 83.792    | 85.993    | 88.194    | 90.395    | 92.596    | 94.797    | 96.998    | 99.199    | 101.400   | 103.601   | 105.802   | 108.003   | 110.204   |
|                        | Current Account Balance | 67.645    | 57.256    | 60.376    | 63.496    | 66.616    | 69.736    | 72.856    | 75.976    | 79.096    | 82.216    | 85.336    | 88.456    | 91.576    | 94.696    | 97.816    | 100.936   |
| 07. Chapter<br>x1000\$ | Export                  | 2.445.822 | 1.877.031 | 1.944.644 | 2.012.257 | 2.079.870 | 2.147.483 | 2.215.096 | 2.282.709 | 2.350.322 | 2.417.935 | 2.485.548 | 2.553.161 | 2.620.774 | 2.688.387 | 2.756.000 | 2.823.613 |
|                        | Import                  | 1.266.184 | 884.638   | 924.049   | 963.460   | 1.002.871 | 1.042.282 | 1.081.693 | 1.121.104 | 1.160.515 | 1.199.926 | 1.239.337 | 1.278.748 | 1.318.159 | 1.357.570 | 1.396.981 | 1.436.392 |
|                        | Current Account Balance | 1.179.638 | 992.393   | 1.020.595 | 1.048.797 | 1.076.999 | 1.105.201 | 1.133.403 | 1.161.605 | 1.189.807 | 1.218.009 | 1.246.211 | 1.274.413 | 1.302.615 | 1.330.817 | 1.359.019 | 1.387.221 |
| 08. Chapter<br>x1000\$ | Export                  | 5.368.161 | 5.705.527 | 5.890.150 | 6.074.773 | 6.259.396 | 6.444.019 | 6.628.642 | 6.813.265 | 6.997.888 | 7.182.511 | 7.367.134 | 7.551.757 | 7.736.380 | 7.921.003 | 8.105.626 | 8.290.249 |
|                        | Import                  | 1.263.038 | 1.075.700 | 1.123.204 | 1.170.708 | 1.218.212 | 1.265.716 | 1.313.220 | 1.360.724 | 1.408.228 | 1.455.732 | 1.503.236 | 1.550.740 | 1.598.244 | 1.645.748 | 1.693.252 | 1.740.756 |
|                        | Current Account Balance | 4.105.123 | 4.629.827 | 4.766.946 | 4.904.065 | 5.041.184 | 5.178.303 | 5.315.422 | 5.452.541 | 5.589.660 | 5.726.779 | 5.863.898 | 6.001.017 | 6.138.136 | 6.275.255 | 6.412.374 | 6.549.493 |
| 09. Chapter<br>x1000\$ | Export                  | 318.923   | 283.318   | 294.203   | 305.088   | 315.973   | 326.858   | 337.743   | 348.628   | 359.513   | 370.398   | 381.283   | 392.168   | 403.053   | 413.938   | 424.823   | 435.708   |
|                        | Import                  | 620.242   | 451.933   | 473.550   | 495.167   | 516.784   | 538.401   | 560.018   | 581.635   | 603.252   | 624.869   | 646.486   | 668.103   | 689.720   | 711.337   | 732.954   | 754.571   |
|                        | Current Account Balance | -301.319  | -168.615  | -179.347  | -190.079  | -200.811  | -211.543  | -222.275  | -233.007  | -243.739  | -254.471  | -265.203  | -275.935  | -286.667  | -297.399  | -308.131  | -318.863  |

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Table 4. Continue

| Products / Years       |                            | 2023       | 2024       | 2025       | 2026       | 2027       | 2028       | 2029       | 2030       | 2031       | 2032       | 2033       | 2034       | 2035       | 2036       | 2037       | 2038       |
|------------------------|----------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 10. Chapter<br>x1000\$ | Export                     | 1.732.472  | 1.012.368  | 1.138.804  | 1.272.918  | 1.414.710  | 1.564.180  | 1.721.328  | 1.886.154  | 2.058.658  | 2.238.840  | 2.426.700  | 2.622.238  | 2.825.454  | 3.036.348  | 3.254.920  | 3.481.170  |
|                        | Import                     | 5.075.074  | 4.156.076  | 4.341.990  | 4.527.904  | 4.713.818  | 4.899.732  | 5.085.646  | 5.271.560  | 5.457.474  | 5.643.388  | 5.829.302  | 6.015.216  | 6.201.130  | 6.387.044  | 6.572.958  | 6.758.872  |
|                        | Current Account<br>Balance | -3.342.602 | -3.143.708 | -3.203.186 | -3.254.986 | -3.299.108 | -3.335.552 | -3.364.318 | -3.385.406 | -3.398.816 | -3.404.548 | -3.402.602 | -3.392.978 | -3.375.676 | -3.350.696 | -3.318.038 | -3.277.702 |
| 11. Chapter<br>x1000\$ | Export                     | 1.876.056  | 1.817.360  | 1.892.567  | 1.967.774  | 2.042.981  | 2.118.188  | 2.193.395  | 2.268.602  | 2.343.809  | 2.419.016  | 2.494.223  | 1.817.360  | 1.892.567  | 1.967.774  | 2.042.981  | 2.118.188  |
|                        | Import                     | 244.485    | 208.262    | 218.230    | 228.198    | 238.166    | 248.134    | 258.102    | 268.070    | 278.038    | 288.006    | 297.974    | 307.942    | 317.910    | 327.878    | 337.846    | 347.814    |
|                        | Current Account<br>Balance | 1.631.571  | 1.609.098  | 1.674.337  | 1.739.576  | 1.804.815  | 1.870.054  | 1.935.293  | 2.000.532  | 2.065.771  | 2.131.010  | 2.196.249  | 1.509.418  | 1.574.657  | 1.639.896  | 1.705.135  | 1.770.374  |
| 12. Chapter<br>x1000\$ | Export                     | 639.716    | 589.517    | 615.361    | 641.205    | 667.049    | 692.893    | 718.737    | 744.581    | 770.425    | 796.269    | 822.113    | 847.957    | 873.801    | 899.645    | 925.489    | 951.333    |
|                        | Import                     | 299.001    | 301.657    | 313.640    | 325.622    | 337.605    | 349.587    | 361.570    | 373.553    | 385.535    | 397.518    | 409.500    | 421.483    | 433.466    | 445.448    | 457.431    | 469.413    |
|                        | Current Account<br>Balance | 340.715    | 287.860    | 301.721    | 315.583    | 329.444    | 343.306    | 357.167    | 371.028    | 384.890    | 398.751    | 412.613    | 426.474    | 440.335    | 454.197    | 468.058    | 481.920    |
| 13. Chapter<br>x1000\$ | Export                     | 16.184     | 27.749     | 29.095     | 30.441     | 31.787     | 33.133     | 34.479     | 35.825     | 37.171     | 38.517     | 39.863     | 41.209     | 42.555     | 43.901     | 45.247     | 46.593     |
|                        | Import                     | 81.252     | 69.654     | 71.852     | 74.050     | 76.248     | 78.446     | 80.644     | 82.842     | 85.040     | 87.238     | 89.436     | 91.634     | 93.832     | 96.030     | 98.228     | 100.426    |
|                        | Current Account<br>Balance | -65.068    | -41.905    | -42.757    | -43.609    | -44.461    | -45.313    | -46.165    | -47.017    | -47.869    | -48.721    | -49.573    | -50.425    | -51.277    | -52.129    | -52.981    | -53.833    |
| 14. Chapter<br>x1000\$ | Export                     | 33.953     | 29.964     | 31.359     | 32.823     | 34.355     | 35.954     | 37.621     | 39.356     | 41.159     | 43.029     | 44.967     | 46.974     | 49.047     | 51.189     | 53.399     | 55.675     |
|                        | Import                     | 14.941     | 16.199     | 16.842     | 17.484     | 18.127     | 18.769     | 19.412     | 20.055     | 20.697     | 21.340     | 21.982     | 22.625     | 23.268     | 23.910     | 24.553     | 25.195     |
|                        | Current Account<br>Balance | 19.012     | 13.765     | 14.518     | 15.339     | 16.228     | 17.185     | 18.209     | 19.301     | 20.461     | 21.689     | 22.985     | 24.349     | 25.780     | 27.279     | 28.846     | 30.480     |



#### 4. Conclusions

In the shadow of global food crises caused or potentially caused by climate change, wars, and various global disasters, special attention must be given to the agricultural sector. This is essential not only to develop domestic agriculture but also to play a significant role in ensuring the country's rural and economic development. Alongside the industrial sector, Turkey possesses the potential to become a major agricultural power through structural transformations in the agricultural sector. The establishment of a sustainable agricultural system will contribute to rural development as well as to the creation of a sustainable current account balance in foreign trade. Therefore, the foreign trade performance of agricultural products must be meticulously analyzed and evaluated through a holistic approach.

This study aims to uncover the current situation and future potential of the sector by examining Turkey's foreign trade projections for agricultural crop-based product groups. The analyses were carried out for 9 product groups between Chapters 06-14 under Section 2 of the Customs Tariff Schedule.

As a matter of fact, the projection analysis also shows that there are increases by chapters. Accordingly, in line with the future projections for Turkey's plant product group: Chapter 6 live trees and other plants and Chapter 7 vegetables product group may have a current account surplus by 2038. Higher exports compared to imports in these product groups may lead to a favourable trade balance. Chapter 8 fruits product group has the highest current account surplus. In this chapter, exports have a significant advantage over imports. This shows that the agricultural sector is strong in fruit production. Chapter 9 tea, coffee and spices has a current account deficit, but imports are likely to increase in the long run as the growth rate of imports is higher than exports. Chapter 10 cereals has a significant current account deficit. Despite the increase in exports, the value of imports is almost double, which points to a significant problem. In Chapter 11 milling products, exports are expected to significantly exceed imports, leading to a current account surplus. Chapter 12 oilseeds and fruits is expected to post a current account surplus, but the growth rate of imports is higher than the growth rate of exports. Therefore, the values should be monitored carefully as import growth may increase further in the long term. In Chapter 13 lacquers, gums and resins, although the growth rate of exports is high, the value of imports is twice that of exports, leading to a current account deficit. In Chapter 14 vegetable materials for knitting are also expected to post a current account surplus. In line with the results of the analysis or the current foreign trade figures, policies and support programs to encourage domestic production in import-dependent sectors such as cereals and oilseeds are crucial. In addition, training and incentives for exporting both individuals and institutions should also be prioritized to maintain and increase market shares in sectors that are competitive in exports.

In conclusion, Turkey's agricultural foreign trade balance can be restored to a sustainable structure by identifying and protecting existing areas of strength and implementing structural transformation policies in high risk product groups. Thus, by supporting export-oriented agricultural production, important steps can be taken towards both economic development and rural development.

In this direction, some implications can be drawn for Turkey. First of all, policies to support rural development need to be adopted. Enhancing productivity in agricultural production and foreign trade requires training programs for farmers focused on modern agricultural techniques. Infrastructure investments and improved logistics in rural areas will facilitate product access to target markets, increasing export competitiveness. Furthermore, promoting the adoption of innovative technologies in agricultural production processes will improve product quality while reducing costs. According to OECD, providing quality and affordable digital connectivity in rural areas can future-proof rural economies, enabling them to reap the potential benefits from digitalization, climate change and innovation. It also contributes to more efficient and cheaper ways of delivering services (Anonymous, 2022b).

Overall, this study contributes to the literature by providing a product group-based projection analysis of Turkey's agricultural foreign trade and interpreting its implications for rural development from an economic perspective. One of the limitations of this study is its exclusive focus on the economic dimension of rural development. Social, political, and institutional dimensions have been excluded from the scope. Future research could explore a more integrated model by incorporating multiple dimensions of rural development and conducting comparative country analyses.

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### **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study

### **Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

### **Authorship Contribution Statement**

Concept: Gürbüzer, G. B.; Çiftci, F., Design: Gürbüzer, G. B.; Çiftci, F., Data Collection or Processing: Gürbüzer, G. B., Statistical Analyses: Çiftci, F., Literature Search: Gürbüzer, G. B.; Çiftci, F., Writing, Review and Editing Gürbüzer, G. B.; Çiftci, F.

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## ARAŞTIRMA MAKALESİ

## RESEARCH ARTICLE

Farklı Azot Dozu ve Tohum Miktarlarının Kültür (*Triticum aestivum* L.) ve Yabani Buğdaylarda (*Triticum monococcum* L. ve *Triticum turgidum* var. *Mirabile*) Kalite Özellikleri Üzerine Etkisi\*Effect of Different Nitrogen Doses and Seed Amounts on Quality Characteristics in Cultivated (*Triticum aestivum* L.) and Wild Wheats (*Triticum monococcum* L. and *Triticum turgidum* var. *Mirabile*)Murat AKDAĞOĞLU<sup>1\*</sup>, İsmet BAŞER<sup>2</sup>

## Öz

Çalışma, 2022-2023 ve 2023-2024 yıllarında, Tekirdağ Namık Kemal Üniversitesi Ziraat Fakültesi Tarla Bitkileri Bölümü deneme alanlarında yürütülmüştür. Çalışma, Siyez, Dallı buğday ve NKU Zirve genotiplerinde metrekaireye 400-450-500-550 tohum ve 10-15-20 kg da<sup>-1</sup> saf azot dozu kullanılarak bölünmüş parseller deneme desenine göre 3 tekrarlamalı olarak yürütülmüştür. Çalışmada Siyez, Dallı ve NKU Zirve buğdaylarının sedimantasyon, beklemeli sedimantasyon, yaş glüten, glüten indeks ve protein değerleri incelenmiştir. Yapılan analiz sonuçlarına göre protein oranı ve yaş glüten değeri Siyez ve Dallı buğdayda yüksek bulunurken, NKU Zirve ekmeklik buğday genotipinde ise sedimantasyon, beklemeli sedimantasyon ve glüten indeks değerlerinin daha yüksek olduğu tespit edilmiştir. Ekim sıklıkları dikkate alındığında en yüksek sedimantasyon değeri 27.33 ml ile metrekaireye 500 tohum ekim sıklığından elde edilmiştir. Azot dozu uygulamalarına bakıldığında, en yüksek sedimantasyon değeri 27.86 ml ile 20 kg da<sup>-1</sup> saf azot uygulamasında, en düşük sedimantasyon değeri ise 24.72 ml ile 10 kg da<sup>-1</sup> saf azot dozu uygulamasında tespit edilmiştir. Ekim sıklıklarına bakıldığında en yüksek beklemeli sedimantasyon 29.57 ml ile metrekaireye 500 tohumda, en düşük ise 27.96 ml ile metrekaireye 450 tohumda, azot dozu uygulamalarına bakıldığında en yüksek beklemeli sedimantasyon değeri 29.56 ml ile 20 kg da<sup>-1</sup> uygulamasında tespit edilmiştir. Ekim sıklıklarına bakıldığında en yüksek yaş glüten değeri %41.32 ile metrekaireye 500 tohumda, azot dozu uygulamalarındaki en yüksek yaş glüten %41.06 ile 20 kg da<sup>-1</sup>, en düşük %38.51 ile 10 kg da<sup>-1</sup> saf azot dozu uygulamasında tespit edilmiştir. Ekim sıklıklarına bakıldığında en yüksek glüten indeksi değeri %81.62 ile metrekaireye 550 tohumda, azot dozu uygulamalarındaki en yüksek yaş glüten değeri %74.37 ile 10 kg da<sup>-1</sup>, en düşük ise %72.22 ile 20 kg da<sup>-1</sup> saf azot dozu uygulamasında tespit edilmiştir. Ekim sıklıklarına bakıldığında en yüksek protein oranı %16.37 ile metrekaireye 450 tohumda, azot dozu uygulamalarındaki en yüksek protein ise %16.70 ile 20 kg da<sup>-1</sup> saf azot uygulamasında, en düşük azot doz ortalaması ise %15.43 ile 10 kg da<sup>-1</sup> saf azot dozu uygulamasında tespit edilmiştir.

**Anahtar Kelimeler:** Dallı buğday, Siyez, Ekim normu, Azot dozu, Yerel buğday

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## Abstract

The study was conducted in 2022-2023 and 2023-2024 in the experimental fields of Tekirdağ Namik Kemal University, Faculty of Agriculture, Department of Field Crops. The study was carried out in Siyez, Dallı wheat and NKU Zirve genotypes using 400-450-500-550 seeds per square meter and 10-15-20 kg da-1 pure nitrogen dose according to split-plot experimental design with 3 replications. In the study, the normal Zeleny sedimentation, delayed Zeleny sedimentation, wet gluten, gluten index and protein values of Siyez, Dallı and NKU Zirve wheats were analysed. According to the results of the analyses, it was found that protein ratio and wet gluten values were higher in Siyez and Dallı wheat, while Zeleny sedimentation, delayed Zeleny sedimentation and gluten index values were higher in NKU Zirve bread wheat genotype. Considering the sowing frequencies, the highest Zeleny sedimentation value was obtained from 500 seeds per square metre sowing amounts with 27.33 ml. Considering the nitrogen dose applications, the highest sedimentation value was found in 20 kg da-1 pure nitrogen application with 27.86 ml and the lowest sedimentation value was found in 10 kg da-1 pure nitrogen dose application with 24.72 ml. Considering the sowing amounts, the highest delayed sedimentation value was 29.57 ml at 500 seeds per square meter and the lowest was 27.96 ml at 450 seeds per square metre, and the highest delayed sedimentation value was 29.56 ml at 20 kg da-1 application. Considering the sowing amounts, the highest wet gluten value was determined at 500 seeds per square meter with 41.32%, the highest wet gluten value was determined at 20 kg da-1 with 41.06% and the lowest was determined at 10 kg da-1 pure nitrogen dose application with 38.51%. Considering the sowing amounts, the highest gluten index value was determined at 550 seeds per square metre with 81.62%, the highest wet gluten value was determined at 10 kg da-1 with 74.37% and the lowest was determined at 20 kg da-1 pure nitrogen dose application with 72.22%. Considering the sowing amounts, the highest protein rate was determined in 450 seeds per square meter with 16.37%, the highest protein in nitrogen dose applications was determined in 20 kg da-1 pure nitrogen application with 16.70%, and the lowest nitrogen dose average was determined in 10 kg da-1 pure nitrogen dose application with 15.43%.

**Keywords:** *T. turgidum* var. *Mirabile*, *T. monococcum* L., Seed rates, Nitrogen dose, Local wheat



## 1. Giriş

İnsanoğlu, varoluşundan bu yana hayatta kalabilmek için en temel önceliği olarak her zaman beslenmeyi görmüştür. İlk çağlardan itibaren, beslenme gereksinimi bitkisel ve hayvansal olmak üzere iki ana kaynaktan karşılanmıştır. Bitkisel kaynaklardan sağlanan beslenme alışkanlığı, insanlık tarihi boyunca gelişim göstererek zamanla tarımsal üretime dönüşmüştür. Tarla bitkilerinin genetik kökeni ve yayılma alanı olarak da bilinen Anadolu toprakları, tarımın doğduğu ve binlerce yıldır zirai faaliyetlerin kültür ve gelenek haline geldiği bir merkez niteliğindedir. Buğday, özellikle ekmek olmak üzere buğdaydan elde edilen ürünlerle geçmişten günümüze ülkemiz insanının temel besin kaynağı olmuştur. Taşıdığı bu önemli rol sayesinde, buğday daima değerli kabul edilmiş, saygı gösterilmiş ve kutsal bir ürün olarak görülmüştür. Ülkemizde mevcut tarım alanlarının yalnızca %20'sinde sulama yapılabilmekte, geri kalan alanlarda ise kuru tarım uygulanmaktadır. Bu durum, özellikle kuru tarım yöntemiyle üretilen tarla bitkilerinin önemini daha da vurgulamaktadır. Neolitik dönemde, Çatalhöyük'teki mağaralarda kurulan ilk tarım köylerinde iki buğday türü 14 kromozomlu einkorn (siyez) (*Triticum monococcum*) ve 28 kromozomlu emmere (gernik) (*Triticum dicoccum*) rastlanmıştır. İlerleyen dönemlerde ise iri taneli, uzun boylu ve kavuzsuz yapıları sayesinde daha kolay işlenebilen 28 kromozomlu makarnalık buğday (*Triticum durum*) ile 42 kromozomlu ekmeklik buğday (*Triticum aestivum*) türleri gelişmiştir (Bilgiç, 2004; Yıldırım, 2004). Buğday, yalnızca bir besin kaynağı olmanın ötesine geçerek, zamanla küresel ölçekte stratejik bir ürün haline gelmiştir. Buğdayın besin değerine yönelik yapılan analizler, bu temel gıdanın insan diyetindeki kalori ve protein ihtiyacının önemli bir bölümünü karşıladığını ortaya koymaktadır. Ayrıca, yüksek karbonhidrat içeriğiyle enerji sağlamada kritik bir rol üstlenmesinin yanı sıra, buğday ve buğday ürünlerinin protein, yağ, çeşitli mineraller ve vitaminler gibi hayati besin maddelerini de içerdiği tespit edilmiştir (Menderis, 2006).

Öncan ve ark. (2010) bitki sıklığı ve azot dozlarının buğdayda verim ve kalite özelliklerine etkisinin araştırdığı bir çalışmada azot gübre dozları olarak (0–8–16–24) kg da<sup>-1</sup> ve farklı bitki sıklıkları olarak da metre kareye 300–500–700 bitki kullanmışlardır. Sonuçta, yüksek verim için denemenin yürütüldüğü her iki yılda da 16 kg da<sup>-1</sup> azot dozunu daha ekonomik bulmuşlardır. Bitki sıklıkları arasında ise 500 bitki sıklığının uygun olduğunu belirlemişlerdir. Kalite sonuçlarında ise 24 kg da<sup>-1</sup> azot dozuna kadar artış olduğunu bildirmişler ancak 24 kg da<sup>-1</sup> gibi yüksek bir azot dozuna kadar çıkılmasına rağmen protein oranı istenilen düzeye taşınmadığını belirtmişlerdir. Yaş glüten değerinde ise incelenen çeşitlerde iyi sonuçlar elde etmişler ve kalite değerlerinde 300 veya 500 bitki sıklığında en yüksek sonuçlara ulaşıldığını ortaya koymuşlardır. Bitkilerin azota tepkisi, bitki besleme konusunun en önemli faktörlerinden biridir. Çünkü farklı dozdaki azotların bitkilerde verim, bitki boyu vb. tüm etkenleri etkileyebileceği bilinmektedir. Bu nedenle farklı azot dozu uygulamalarının bitki üzerinde oluşturacağı farklı etkileri incelemek çok önemlidir. Son yıllarda küresel iklim değişiminin etkisi ile artan sıcaklıklar ve sık görülmeye başlayan kuraklıklar abiyotik ve biyotik streslerden daha az etkilenen genotiplerin özellikle kuraklığın daha etkin görüldüğü alanlar için göz önüne alınması gerektiğini göstermektedir.

Almanya'da dört farklı lokasyonda gerçekleştirilen bir çalışmada, siyez, gernik ve spelt gibi kavuzlu buğday türlerinin modern buğdaylarla karşılaştırılması amacı güdülmüştür. Elde edilen bulgular, siyez, gernik ve spelt'in dane verimlerinin ekmeklik buğdaya göre sırasıyla %37, %55 ve %62 oranında daha düşük olduğunu ortaya koymuştur. Ayrıca, kavuzlu buğdayların ekmeklik ve makarnalık buğdaylara kıyasla yaklaşık 30 cm daha uzun bitki boyuna sahip olduğu rapor edilmiştir (Longin ve ark., 2016). Azotlu gübrelemenin, buğdayın birim alan verimini ve ürün kalitesini artırmak için üreticiler tarafından kolaylıkla kontrol edilebilen en etkili yetiştirme tekniklerinden biri olduğu belirtilmiştir. Bu durum, azotun bitki gelişimi ve verimliliği üzerindeki önemli etkisini vurgulamakta ve üreticilere, bu tür gübre uygulamalarını dikkate alarak daha iyi sonuçlar elde edebileceklerini göstermektedir (Koç ve Genç, 1990). Sağlam (1999) Tekirdağ ekolojik koşullarında yapılan bir çalışmada, yabancı kökenli beş ekmeklik buğday çeşidine 6 farklı azot dozu (0, 4, 8, 12, 16, 20 kg da<sup>-1</sup>) uygulanmıştır. Araştırma sonucunda, en yüksek tane verimi 16 kg da<sup>-1</sup> saf azot uygulamasında elde edilmiştir. Ayrıca bu azot dozunun en ekonomik uygulama olduğu vurgulanmıştır. Bu sonuç, buğday üretiminde verim artışı sağlamak için azot gübrelemesinin optimal seviyede tutulmasının önemini ortaya koymaktadır. Avustralya'da gerçekleştirilen bir araştırmada, iki ekmeklik buğday çeşidine 0, 25 ve 50 kg ha<sup>-1</sup> azot dozları, farklı zamanlarda uygulanmış olup, buğdayın kalite özelliklerini optimize etmek için farklı azot miktarları uygulamanın önemli olduğunu vurgulamıştır (Ferrari ve ark., 2016). Kısa (2018), Hatay koşullarında üç farklı ekim sıklığını (metrekareye 450, 550 ve 650 tohum, protein oranı için %18.34-17.02-16.8 ve glüten oranı için ise %12.1-17.7-12.1 olarak belirlemiştir. Kastamonu ilinde temin edilen siyez buğday popülasyonunda dört ekim sıklığı (metrekareye 300,

400, 500, 600 tohum) ile beş farklı azot dozunun denendiği bir çalışmada (0, 5, 10, 15, 20 kg da<sup>-1</sup>) protein oranı ortalama %10.74, sedimantasyon ortalama 23.90 ml, olarak belirlemiş ve kalite kriterlerinden protein oranı için en uygun kombinasyonun ise 10 kg N kg da<sup>-1</sup> azot dozu ve 500 tohum m<sup>2</sup> ekim sıklığı olduğu bildirilmiştir (Erdoğan, 2023). Kastamonu ilinden toplanan siyez ve gernik buğdaylarının morfolojik ve fenolojik özelliklerini belirlemek amacıyla yürütülen çalışmada, protein oranı %18.13 olarak tespit edilmiştir (Demirel ve ark., 2019).

Mardin İli Artuklu İlçesinde yapılan bir çalışmada kullanılan yerel çeşitlerin, kalite değerlendirilmesinde en önemli kriter olan protein oranı bakımından kontrol çeşitlerine bariz bir üstünlüğünün olduğunu, bu yerel çeşitlerin tane protein oranının artırılmasında kullanılabilecek çok değerli genotipler olduğu tespit edilmiştir (Aktaş ve Durmaz, 2023). Yerel ekmeklik buğday popülasyonları ile ilgili yapılan çalışmada, yerel ekmeklik buğday çeşitlerinin kalite açısından önemli genetik kaynaklar olduğu ve ıslah programlarında kullanım açısından önemli potansiyele sahip oldukları belirlenmiştir (Mut ve ark., 2024). Yapılan bir araştırmada Çanakkale, Balıkesir ve Kars İllerindeki öncü çiftçi/tüketici toplulukları ile İzmir ilinde yerel buğday çeşitleri ile ekmek ve diğer ürünlerin yaygınlaştırılmasında faaliyet gösteren bazı topluluk destekli tarım grupları incelenmiştir. İnceleme sonucunda tüketici gruplarda üretim sürecini anlamanın ve odak grup çalışmaları ile tüketime dair sorunların belirlenmesinin ilk olarak yerel buğday ürünleri tüketimini arttırdığı tespit edilmiştir (Yıldız ve Özkaya, 2024).

Son yıllarda küresel iklim değişikliğinin artan etkisi nedeniyle birçok bölgede biyotik ve abiyotik streslerin etkisi daha yoğun görülmeye başlamıştır. Artan sıcaklıklar daha sık kuraklık oluşumuna, hastalık ve zararlılarda artışa neden olmaktadır. Farklı ıslah teknikleri kullanılarak ıslah edilmiş modern çeşitlerin çoğu yüksek girdi kullanımı ile bu verimlerine ulaşabilmektedir. Ayrıca değişen iklim koşullarından bu modern çeşitlerin kolay etkilenmesi nedeniyle sürdürülebilir tarım ve sürdürülebilir gıda konusunda riskler olabileceği öngörülmektedir. Yerel genotipler uzun yıllar boyunca mevcut yerel koşullara her zaman adapte olmuş ve yoğun bir girdi kullanımı olmadan verimi düşük topraklarda bile belirli verimleri sağlayabilen genetik materyallerdir. Yerel genotipler, uzun yıllar boyunca yerel koşullara adapte olmuş ve bu nedenle abiyotik ve biyotik streslere daha dayanıklı olan genotiplerdir. Bu bitkiler, doğal seleksiyon ve geleneksel tarım uygulamaları sayesinde çeşitli iklim koşullarına uyum sağlamıştır. Gıda güvenliği ve sürdürülebilirlik konularında artan talepler, yerel bitkilere ve yerel genetik çeşitliliğe yeniden ilgiyi artırmaktadır. Yerel genotipler streslere dayanımları yanında kalite özellikleri yönünden de üstün özellikler taşımaktadırlar. Islah edilmiş çeşitler genellikle verimlilik açısından optimize edilirken, bazı özellikler yönünden ise eksiklikler göstermektedirler. Yerel bitkiler iklim koşullarına uyum sağlamış ve bu koşullarda başarılı olabilen genetik özelliklere sahiptirler. Bu, iklim değişikliğinin getirdiği belirsizliklere karşı daha dayanıklı tarım yöntemleri geliştirmek isteyen çiftçiler için önemli bir avantaj sağlar. Yerel buğday genotipleri üzerinde yapılacak bu araştırmanın; modern ekmeklik buğday genotiplerinin tarımsal üretimdeki önemi göz önüne alındığında, dallı ve siyez buğday genotiplerinin verim, kalite vb. karakterlerinin incelenmesi büyük önem arz etmektedir. Çalışmada yerel buğdaylardan olan dallı ve siyez buğday genotipleri son yıllarda yukarıda bahsedilen nedenlerle ilgi odağı olan buğdaylardır. Dalli ve siyez buğday genotipleri için birim alana atılacak optimum tohum miktarı ve uygun saf azot dozu ile ilgili çalışmalar oldukça azdır. Bu çalışma yerel buğdaylardan olan dallı ve siyez buğday genotiplerinin performansını analiz ederek kombinasyon ıslahı ile geliştirilen NKU Zirve ekmeklik buğday ile karşılaştırıp, tarımsal üretimde verimliliği, farkındalığı, sürdürülebilirliği, doğal ürün üretimini, kaliteyi yükseltebilmek için temel veri sağlamayı hedeflemektedir. Çalışma sonucunda elde edilecek verilerin, gelecekte yapılacak olan araştırmalara, yorumlara, çıkarımlara ve çalışmalara temel olması hedeflenmektedir. Çalışmanın amacı, dallı ve siyez buğdayında farklı ekim normu ve azot dozlarının verim üzerine etkisini belirlemek ve modern buğday genotipi olan NKU Zirve ile de karşılaştırmaktır.

## 2. Materyal ve Metot

### 2.1. Materyal

Araştırmanın yürütüldüğü 2022-2023 ve 2023-2024 yetiştirme yılları için kullanılan siyez buğdayı Ankara Tohumluk Tescil ve Sertifikasyon Müdürlüğünden, dallı buğday ve NKU Zirve buğdayları ise 2022 yılında Tekirdağ Namık Kemal Üniversitesi, Ziraat Fakültesi, Tarla Bitkileri araştırma ve uygulama alanlarından üretilen buğdaylardan elde edilmiştir.

Deneme ekimleri 2022-2023 yılında 10.12.2022 ve 2023-2024 yılında 10.12.2023 tarihinde, hasat işlemleri 16.07.2023 ve 25.07.2024 tarihlerinde yapılmıştır. Ekim sıklıkları (metrekareye 400, 450, 500, 550 tohum) ve azot dozları (10, 15 ve 20 kg da<sup>-1</sup>) alt parselleri oluşturacak şekilde planlanan denemelerimiz, tesadüf bloklarında

bölünen bölünmüş parseller deneme desenine göre 3 tekrarlamalı olarak, iki yıl (2022- 2023 ve 2023-2024 yetiştirme dönemi) yürütülmüştür. Denemelerde ekimler 6.12 metrekare (6 metre uzunluğunda 6 sıradan oluşan ve sıra arası açıklıkları 17 cm) olan parsellere deneme mibzeri ile yapılmış ve hasatta 5.1 metrekarelik alan hasat edilmiştir. Yapılan araştırmalar, Trakya Bölgesi'nde buğday yetiştiriciliğinde bölgenin potansiyel buğday verimine ulaşmada 16 kg da<sup>-1</sup> saf azot uygulanması gerektiğini ortaya koymuştur (Güçdemir, 2006). Buradan hareketle, denemede 3 farklı azot dozu uygulaması yapılmıştır. 10 kg da<sup>-1</sup>, 15 kg da<sup>-1</sup> ve 20 kg da<sup>-1</sup> saf azotun 5 kg'lık kısmı, tüm parsellere ekim ile birlikte 20.20.0 kompoze gübresi ile taban gübresi şeklinde verilmiştir. Geriye kalan saf azot uygulamaları ise üst gübre olarak Zadoks skalasındaki büyüme- gelişme dönemleri ve yağışlar dikkate alınarak 4 değişik şekilde uygulanmıştır (Tablo 1).

**Tablo 1. Gübreleme uygulamaları**

*Table 1. Fertilization applicatipons*

| Uygulamalar | Ekim İle Birlikte           | Kardeşlenme Başlangıcı (Zadoks 21) | Kardeşlenme Sonu (Zadoks 25)      | Sapa Kalkma Sonu (Zadoks 37)      |
|-------------|-----------------------------|------------------------------------|-----------------------------------|-----------------------------------|
| <b>10</b>   | 5 kg da <sup>-1</sup> saf N | 5 kg da <sup>-1</sup> saf N (Üre)  | -                                 | -                                 |
| <b>15</b>   | 5 kg da <sup>-1</sup> saf N | 6 kg da <sup>-1</sup> saf N (Üre)  | 4 kg da <sup>-1</sup> saf N (Üre) | -                                 |
| <b>20</b>   | 5 kg da <sup>-1</sup> saf N | 7 kg da <sup>-1</sup> saf N (Üre)  | 4 kg da <sup>-1</sup> saf N (Üre) | 4 kg da <sup>-1</sup> saf N (Üre) |

İlk gübreleme ekim ile birlikte, kardeşlenme başlangıcındaki (Zadoks 21. dönem) gübreleme 15 Şubat, kardeşlenme sonundaki (Zadoks 25. dönem) gübreleme 15 Mart, son gübreleme sapa kalkma sonunda (Zadoks 37. dönem) yani 15 Nisan'da yapılmıştır. Yabancı ot mücadelesi amacıyla ara yollar rotavator ile işlenmiş, parsel üzerine ve parsel aralarına ise farklı dönemlerde herbisit uygulamaları yapılmıştır. Siyez buğdayını herhangi bir herbisit uygulaması yapılmamıştır. Siyez buğdayında yabancı ot mücadelesi el ile gerçekleştirilmiştir. Hasat işlemleri ise her iki yılda parsel biçerdöveri ile yapılmıştır.

## 2.2. İstatistiksel Analizler

Denemeden elde edilen veriler Bölünen Bölünmüş Parseller Deneme Desenine göre Tarist bilgisayar programı ile varyans analizi yapılmıştır. Denemede incelenen özelliklerin ortalama değerleri arasındaki farkların istatistiki anlamda önemlilikleri DUNCAN testine göre belirlenmiştir.

## 3. Araştırma Sonuçları ve Tartışma

### 3.1. Sedimentasyon (ml)

Buğday ve unun ekmek olabilmek için hangi kalitede olduğunu belirleyebilmede önemli kalite kriteri olarak yapılan testtir. Deneme sonuçları incelendiğinde genotipler, sıklık ve azot dozları, genotip x sıklık interaksyonu, sıklık x azot dozu interaksyonu ve genotip x sıklık x azot dozu interaksyonu istatistiki olarak %0.01 düzeyinde, genotip x azot dozu interaksyonu istatistiki olarak %0.05 düzeyinde önemli bulunmuştur. Genotip, tohum miktarı ve azot dozları ortalamaları ve önemlilik gruplamaları Tablo 2'de verilmiştir.

**Tablo 2. Genotip, tohum miktarı ve azot dozlarına göre sedimentasyon değerleri (ml)**

*Table 2. Zeleny Sedimentation values according to genotype, seed amounts and nitrogen doses (ml)*

| Genotip          | Ortalama ve Önemlilik | Sıklık     | Ortalama ve Önemlilik | Doz       | Ortalama ve Önemlilik |
|------------------|-----------------------|------------|-----------------------|-----------|-----------------------|
| <b>Siyez</b>     | 24.37 b               | <b>400</b> | 26.55 ab              | <b>10</b> | 24.72 c               |
| <b>Dallı</b>     | 11.94 b               | <b>450</b> | 25.55 c               | <b>15</b> | 26.38 b               |
| <b>NKU Zirve</b> | 42.65 a               | <b>500</b> | 27.33 a               | <b>20</b> | 27.86 a               |
|                  |                       | <b>550</b> | 25.85 bc              |           |                       |

En yüksek sedimentasyon değeri 42.65 ml ile NKU Zirve genotipinde ölçülmüş, bunu 24.37 ml ile siyez buğday genotipi ve 11.94 ml ile dallı buğday genotipi takip etmiştir. En yüksek sıklık ortalaması 27.33 ml ile metrekareye 500 tohumda, bunu 26.55 ve 25.85 ml ile metrekareye 400 ve 550 ekim sıklığı takip etmiştir. Sedimentasyonun en yüksek olduğu azot dozu ortalaması ise 27.86 ml ile 20 kg da<sup>-1</sup> saf azot uygulamasında

ölçülmüştür. En düşük azot doz ortalaması ise 24.72 ml ile 10 kg da<sup>-1</sup> saf azot dozu uygulamasında tespit edilmiştir (Tablo 2). Genotip x tohum miktarı x azot dozları, interaksyonu ortalamaları ve önemlilik gruplamaları Tablo 3’de verilmiştir.

**Tablo 3. Genotip x tohum miktarı x azot dozu interaksyonlarına göre sedimantasyon değeri ortalamaları ve önemlilikleri (ml)**

Table 3. Means and significance of Zeleny sedimentation value according to genotype x seed amount x nitrogen dose interactions (ml)

| Genotip   | Sıklık | Azot Dozu |           |          | Ortalama |
|-----------|--------|-----------|-----------|----------|----------|
|           |        | 10        | 15        | 20       |          |
| Siyez     | 400    | 26.66 e   | 26.83 e   | 25.16 e  | 26.21    |
|           | 450    | 22.16 e   | 24.50 e   | 24.33 e  | 23.66    |
|           | 500    | 24.00 e   | 23.33 e   | 24.83 e  | 24.05    |
|           | 550    | 23.33 e   | 25.33 e   | 25.00 e  | 24.55    |
| Dallı     | 400    | 9.66 g    | 11.66 fg  | 11.50 fg | 10.94    |
|           | 450    | 10.66 g   | 9.50 g    | 15.00 fg | 11.72    |
|           | 500    | 11.33 fg  | 16.66 f   | 15.00 fg | 14.33    |
|           | 550    | 10.66 g   | 10.50 g   | 11.16 fg | 10.77    |
| NKU Zirve | 400    | 47.50 a   | 44.50 abc | 38.50 d  | 43.50    |
|           | 450    | 36.00 d   | 40.50 bcd | 47.33 a  | 41.27    |
|           | 500    | 38.33 d   | 45.50 ab  | 47.00 a  | 43.61    |
|           | 550    | 39.33 cd  | 37.83 d   | 49.50 a  | 52.22    |

Genotip x tohum miktarı x azot dozu interaksyonu incelendiğinde en yüksek sedimantasyon değeri 49.50 ml ile NKU Zirve genotipinin metrekaireye 550 tohum miktarında ve 20 kg da<sup>-1</sup> saf azot uygulamasında, dallı buğday genotipinde 16.66 ml ile metrekaireye 500 tohum miktarında ve 15 kg da<sup>-1</sup> saf azot uygulamasında, siyez buğday genotipinde ise 26.83 ml ile metrekaireye 400 ekim sıklığında ve 15 kg da<sup>-1</sup> saf azot uygulamasında elde edilmiştir (Tablo 3).

Sedimantasyon değeri, buğdayın glüten kalitesini ve unun işlenebilirliğini değerlendiren önemli bir kalite parametresidir. 30 ml ve üzeri sedimantasyon değeri gösteren unlar ekmek yapımı için çok iyi değere sahip kaliteli olarak değerlendirilir. 15-20 ml arası sedimantasyon değeri olan unlar zayıf, 20-25 ml orta olarak değerlendirilirken 25-30 ml arası sedimantasyon değeri ise ekmek yapımına uygun iyi kalite olarak değerlendirilmektedir (Ünal, 2003). Yüksek sedimantasyon değeri, buğdayın glüten kalitesinin yüksek olduğunu ve dolayısıyla ekmeklik un üretimi için daha uygun olduğunu gösterirken, düşük sedimantasyon değeri glüten kalitesinin zayıf olduğunu ve buğdayın daha çok farklı endüstriyel amaçlarla kullanılabileceğini işaret eder. NKU Zirve genotipinin sedimantasyon değerinin en yüksek olması, bu genotipin glüten kalitesinin yabani genotiplere göre üstün olduğunu göstermektedir. Siyez buğdayının sedimantasyon değeri NKU Zirve genotipine göre daha düşük, ancak dallı buğday genotipine göre daha yüksek olduğu görülmektedir. Siyez buğdayı, genetik olarak abiyotik ve biyotik stres faktörlerine dayanıklı bir tür olması ve glüten kalitesinin orta düzeyde olması, bu genotipin sedimantasyon değeri yüksek kültür çeşitleri ile karıştırılarak un üretimi uygun olabileceği söylenebilir. Dallı buğday genotipinin sedimantasyon değerinin oldukça düşük olması, bu genotipin glüten kalitesinin zayıf olduğunu ve dolayısıyla ekmeklik un üretimi için uygun olmadığını, dallı buğdayın daha çok bisküvilik gibi endüstriyel amaçlarla kullanılabileceği ortaya koymaktadır.

### 3.2. Beklemeli Sedimantasyon (ml)

Genotip, genotip x sıklık x azot dozu interaksyonu, genotip x azot dozu, sıklık x azot dozu interaksyonları istatistiki olarak %0.01 düzeyinde, yıl ve dozlar arasındaki farklılık %0.05 düzeyinde önemli bulunmuştur. Genotip, tohum miktarı ve azot dozları ortalamaları ve önemlilik gruplamaları Tablo 4’de verilmiştir.

**Tablo 4. Genotip, tohum miktarı ve azot dozlarına göre beklemeli sedimantasyon değerleri (ml)**

Table 4. Delayed Zeleny sedimentation values according to genotype, seed amounts and nitrogen doses (ml)

| Genotip          | Ortalama ve Önemlilik | Sıklık     | Ortalama ve Önemlilik | Doz       | Ortalama ve Önemlilik |
|------------------|-----------------------|------------|-----------------------|-----------|-----------------------|
| <b>Siyez</b>     | 26.09 b               | <b>400</b> | 28.81                 | <b>10</b> | 27.86 b               |
| <b>Dallı</b>     | 13.89 b               | <b>450</b> | 27.96                 | <b>15</b> | 28.84 ab              |
| <b>NKU Zirve</b> | 46.29 a               | <b>500</b> | 29.57                 | <b>20</b> | 29.56 a               |
|                  |                       | <b>550</b> | 28.68                 |           |                       |

En yüksek genotip ortalaması 46.29 ml ile NKU Zirve çeşidinde olmuş, bunu 26.09 ml ile siyez buğdayı ve 13.89 ml ile dallı buğday takip etmiştir. En yüksek tohum sıklık ortalaması 29.57 ml ile metrekaireye 500 tohumda, en düşük ise 27.96 ml ile metrekaireye 450 tohum sıklığında tespit edilmiştir. Beklemeli sedimantasyonun en yüksek olduğu azot dozu ise 29.56 ml ile 20 kg da<sup>-1</sup> ile ölçülmüştür (Tablo 4). Genotip x tohum miktarı x azot dozları, interaksyonu ortalamaları ve önemlilik gruplamaları Tablo 5’de verilmiştir.

**Tablo 5. Genotip x tohum miktarı x azot dozu interaksyonuna göre beklemeli sedimantasyon değeri ve önemlilikleri (ml)**

Table 5. Delayed Zeleny sedimentation value and their significance according to genotype x seed amount x nitrogen dose interaction (ml)

| Genotip          | Sıklık | Azot Dozu |           |           | Ortalama |
|------------------|--------|-----------|-----------|-----------|----------|
|                  |        | 10        | 15        | 20        |          |
| <b>Siyez</b>     | 400    | 25.16 fg  | 30.16 f   | 26.83 f   | 27.38    |
|                  | 450    | 23.50 fgh | 27.16 f   | 25.83 fg  | 25.49    |
|                  | 500    | 24.66 fg  | 25.16 fg  | 25.50 fg  | 25.21    |
|                  | 550    | 26.50 fg  | 25.66 fg  | 27.00 f   | 26.38    |
| <b>Dallı</b>     | 400    | 11.66 jk  | 16.66 ijk | 11.33 jk  | 13.21    |
|                  | 450    | 10.16 k   | 9.66 k    | 17.66 hij | 12.49    |
|                  | 500    | 15.50 ijk | 19.66 ghı | 14.50 ijk | 16.55    |
|                  | 550    | 12.33 jk  | 15.33 ijk | 12.16 jk  | 13.27    |
| <b>NKU Zirve</b> | 400    | 38.66 e   | 44.66 b-e | 54.16 a   | 45.82    |
|                  | 450    | 48.50 abc | 39.83 de  | 49.33 abc | 45.88    |
|                  | 500    | 54.00 a   | 42.50 cde | 44.66 b-e | 47.05    |
|                  | 550    | 43.66 b-e | 49.66 ab  | 45.83 bcd | 46.38    |

Genotip x sıklık x azot dozu interaksyonu incelendiğinde en yüksek beklemeli sedimantasyon 54.16 ve 54.00 ml ile NKU Zirve genotipinin metrekaireye 400 ve 500 tohum miktarında ve 20 ve 10 kg da<sup>-1</sup> saf azot uygulamalarından, dallı buğdayda en yüksek beklemeli sedimantasyon 19.66 ml ile metrekaireye 500 tohum uygulaması ve 15 kg da<sup>-1</sup> saf azot uygulamasında, siyez buğday genotipinde ise en yüksek beklemeli sedimantasyon 30.16 ml ile metrekaireye 400 tohum uygulamasında ve 15 kg da<sup>-1</sup> saf azot uygulamalarında elde edilmiştir (Tablo 5).

Beklemeli sedimantasyon değeri, buğdayın un kalitesini ve glüten yapısını değerlendiren önemli bir parametredir. Elde edilen sonuçlar, genotipler arasında ve tohum sıklıklarına ve uygulanan azot dozlarına bağlı olarak belirgin farklılıklar tespit edilmiştir. NKU Zirve genotipinin yüksek glüten kalitesine sahip olduğunu ve ekmeklik buğday olarak kullanım potansiyelinin iyi olduğu, buna karşın dallı buğday genotipinin ise beklemeli sedimantasyon değerlerinin oldukça düşük olduğu dallı buğdayın glüten kalitesinin düşük olduğunu ve dolayısıyla ekmeklik buğday olarak kullanım potansiyelinin olmadığını ortaya koymaktadır. Siyez buğday genotipinin beklemeli sedimantasyon değerleri, NKU Zirve genotipine göre daha düşük, ancak dallı buğday genotipine göre daha yüksek bulunmuştur.

### 3.3. Yaş glüten (%)

Elde edilen varyans analiz sonuçları incelendiğinde yıl, genotipler, azot dozları, genotip x sıklık interaksyonu, genotip x azot dozu interaksyonu, genotip x sıklık x azot dozu interaksyonu ve sıklık x azot dozu interaksyonu



istatistiki olarak %0.01 düzeyinde, sıklıklar arasındaki farklılık istatistiki olarak %0.05 düzeyinde önemli bulunmuştur. Genotip, tohum miktarı ve azot dozları ortalamaları ve önemlilik gruplamaları *Tablo 6*'da verilmiştir.

**Tablo 6. Genotip, tohum miktarı ve azot dozlarına göre yaş glüten oranları (%)**

*Table 6. Wet gluten content (%) according to genotype, seed amount and nitrogen doses*

| Genotip          | Ortalama ve Önemlilik | Sıklık     | Ortalama ve Önemlilik | Doz       | Ortalama ve Önemlilik |
|------------------|-----------------------|------------|-----------------------|-----------|-----------------------|
| <b>Siyez</b>     | 46.84 a               | <b>400</b> | 38.66 b               | <b>10</b> | 38.51 b               |
| <b>Dallı</b>     | 40.08 b               | <b>450</b> | 39.35 ab              | <b>15</b> | 39.10 b               |
| <b>NKU Zirve</b> | 31.75 c               | <b>500</b> | 41.32 a               | <b>20</b> | 41.06 a               |
|                  |                       | <b>550</b> | 38.90 b               |           |                       |

En yüksek yaş glüten ortalaması %46.84 ile siyez buğdayında ölçülmüş, bunu % 40.08 ile dallı buğday ve %31.75 ile NKU Zirve buğday çeşidi takip etmiştir. En yüksek tohum sıklığı gluten ortalaması %41.32 ile metrekareye 500 tohumda olmuş, bunu % 39.35 ve % 38.90 ile metrekareye 450 ve 550 ekim sıklıkları takip etmiştir. Yaş glütenin en yüksek olduğu azot dozu %41.06 ile 20 kg da<sup>-1</sup> olurken, en düşük gluten değeri en düşük azot doz uygulaması olan 10 kg da<sup>-1</sup> saf azot dozu uygulamasında %38.51 olarak belirlenmiştir (*Tablo 6*). Genotip x tohum miktarı x azot dozları, interaksyonu ortalamaları ve önemlilik gruplamaları *Tablo 7*'de verilmiştir.

**Tablo 7. Genotip x tohum miktarı x azot dozu interaksyonlarına göre yaş glüten oranları (%) ve önemlilikleri**

*Table 7. Wet gluten ratios (%) and their significance according to genotype x seed amount x nitrogen dose interactions*

| Genotip          | Sıklık | Azot Dozu |           |           | Ortalama |
|------------------|--------|-----------|-----------|-----------|----------|
|                  |        | 10        | 15        | 20        |          |
| <b>Siyez</b>     | 400    | 42.23 cde | 42.35 cde | 51.70 a   | 45.42    |
|                  | 450    | 50.70 ab  | 48.96 ab  | 46.88 bc  | 48.84    |
|                  | 500    | 48.90 ab  | 49.90 ab  | 50.08 ab  | 49.62    |
|                  | 550    | 43.30 cd  | 44.30 cd  | 42.85 cde | 43.48    |
| <b>Dallı</b>     | 400    | 34.15 f-ı | 38.45 ef  | 42.38 cde | 38.32    |
|                  | 450    | 40.51de   | 40.65 de  | 35.66 fg  | 38.94    |
|                  | 500    | 40.95 de  | 42.76 cde | 43.01 cde | 42.24    |
|                  | 550    | 43.88 cd  | 35.56 fg  | 43.05 cde | 40.83    |
| <b>NKU Zirve</b> | 400    | 31.35 ghı | 30.31 hj  | 35.03 fgh | 32.23    |
|                  | 450    | 26.76 j   | 31.15 g-j | 32.85 ghı | 30.25    |
|                  | 500    | 29.78 ij  | 32.18 ghı | 34.38 f-ı | 32.11    |
|                  | 550    | 29.68 ij  | 32.68 ghı | 34.81 fgh | 32.39    |

Yaş glüten sadece buğdaya özgü olan bir protein çeşididir. Bu protein, ekmek kalitesi bakımından çok büyük bir öneme sahiptir. Yaş glüten, hamurda yoğrulma sırasında ağ gibi bir yapı oluşturur. Fermantasyon sırasında maya tarafından salınan karbondioksit gazının tutulmasını ve hamurun kabarak hacimli olmasını sağladığı için yaş glüten değerinin yüksek olması arzu edilir.

Genotip x sıklık x azot dozu interaksyonu incelendiğinde en yüksek yaş glüten %51.70 ile siyez buğdayının metrekareye 400 adedinde ve 20 kg da<sup>-1</sup> saf azot uygulamasında, NKU Zirve çeşidinde %35.03 ile en yüksek yaş glüten metrekareye 400 tohum miktarı ve 20 kg da<sup>-1</sup> saf azot uygulamasında, dallı buğdayda en yüksek yaş glüten %43.88 ile metrekareye 550 tohum uygulamasında ve 10 kg da<sup>-1</sup> saf azot uygulamasında tespit edilmiştir. En düşük değerler ise siyez buğdayında %42.23 ile en düşük azot dozu uygulaması olan 10 kg saf azot dozunda, dallı buğdayda %34.15 en düşük tohum miktarı olan 400 tohum adedi ve en düşük saf azot dozu olan 10 kg saf azotta olurken, NKU Zirve çeşidinde ise en düşük gluten değeri 450 tohum adedi ve en düşük azot dozu olan 10 kg da<sup>-1</sup> saf azot uygulamasında % 26.76 gluten değeri ile elde edilmiştir (*Tablo 7*). Elde edilen veriler en yüksek glutenin düşük tohum oranında elde edilirken, saf azot uygulamalarının gluten oranını önemli oranda artırdığını ortaya koymaktadır.



Ünal (2002), yaş glüten içeriğinin, unda % 35'in üzerinde yüksek, % 28-35 arası iyi, % 20-27 arası orta ve % 20'nin altında düşük olarak değerlendirildiğini bildirmektedir. NKU Zirve genotipinin yaş glüten değeri optimum aralıkta yer almaktadır. NKU Zirve genotipinin yaş glüten miktarının dengeli olması, hamurun elastikiyet ve esneklik açısından iyi bir performans sergilemesini sağlar. Bu durum, NKU Zirve genotipinin ekmek yapımı için uygun bir potansiyele sahip olduğunu göstermektedir. Siyez ve Dallı buğdayın yaş glüten oranları ise optimum aralığın çok üzerinde yer almaktadır. Bu durum yabancı buğdayların un verimi ve işlenebilirlik açısından sınırlı bir potansiyele sahip olduğunu göstermektedir.

### 3.4. Glüten İndeksi (%)

Genotip x sıklık interaksyonu, sıklık x azot dozu interaksyonu ve genotip x azot dozu interaksyonu istatistiki olarak %0.01 düzeyinde önemli bulunmuştur. Genotip, tohum miktarı ve azot dozları ortalamaları ve önemlilik gruplamaları *Tablo 8*'de verilmiştir.

**Tablo 8. Genotip, tohum miktarı ve azot dozlarına göre glüten indeks değerleri (%) ve önemlilikleri**

Table 8. Gluten index values (%) and their significance according to genotype, seed amount and nitrogen doses

| Genotip   | Ortalama ve Önemlilik | Sıklık | Ortalama ve Önemlilik | Doz | Ortalama ve Önemlilik |
|-----------|-----------------------|--------|-----------------------|-----|-----------------------|
| Siyez     | 70.50                 | 400    | 70.55 b               | 10  | 74.37                 |
| Dallı     | 70.27                 | 450    | 68.37 b               | 15  | 72.48                 |
| NKU Zirve | 78.30                 | 500    | 71.55 b               | 20  | 72.22                 |
|           |                       | 550    | 81.62 a               |     |                       |

En yüksek genotip ortalaması %78.30 ile NKU Zirve genotipinde, en düşük ise %70.27 ile dallı buğdayda tespit edilmiştir. En yüksek tohum miktarı ortalaması %81.62 ile metrekaireye 550 tohumda elde edilmiştir. Glüten indeksinin en yüksek olduğu azot dozu 10 kg saf azot dozunda %74.37 gluten indeksi iken, en düşük gluten indeksi ise en yüksek azot dozu 20 kg da<sup>-1</sup> %72.22 olarak tespit edilmiştir (*Tablo 8*). Genotip x tohum miktarı x azot dozları, interaksyonu ortalamaları ve önemlilik gruplamaları *Tablo 9*'da verilmiştir.

**Tablo 9. Genotip x tohum miktarı x azot dozu interaksyonları ortalama değeri (%) ve önemlilikleri**

Table 9. Mean value (%) and significance of genotype x seed amount x nitrogen dose interactions

| Genotip   | Sıklık | Azot Dozu |       |       | Ortalama |
|-----------|--------|-----------|-------|-------|----------|
|           |        | 10        | 15    | 20    |          |
| Siyez     | 400    | 73.83     | 66.33 | 57.16 | 65.77    |
|           | 450    | 73.66     | 73.66 | 77.66 | 74.99    |
|           | 500    | 67.16     | 47.16 | 61.83 | 58.71    |
|           | 550    | 78.83     | 78.83 | 89.83 | 82.49    |
| Dallı     | 400    | 71.33     | 72.83 | 61.66 | 68.60    |
|           | 450    | 60.16     | 57.66 | 58.83 | 58.88    |
|           | 500    | 77.16     | 72.16 | 75.83 | 75.05    |
|           | 550    | 74.50     | 83.50 | 77.66 | 78.55    |
| NKU Zirve | 400    | 78.50     | 80.33 | 73.00 | 77.27    |
|           | 450    | 72.66     | 70.83 | 70.16 | 71.21    |
|           | 500    | 82.83     | 78.83 | 81.00 | 80.88    |
|           | 550    | 81.83     | 87.66 | 82.00 | 83.83    |

Genotip x sıklık x azot dozu interaksyonu incelendiğinde en yüksek glüten indeks değeri %87.66 ile NKU Zirve çeşidinde metrekaireye 550 tohum adedinde ve 15 kg da<sup>-1</sup> saf azot uygulamasında, dallı buğdayda en yüksek glüten indeks değeri %83.50 ile metrekaireye 550 tohum uygulamasında ve 15 kg da<sup>-1</sup> saf azot uygulamasında, siyez buğdayında ise en yüksek glüten indeks değeri %89.83 ile metrekaireye 550 tohum uygulamasında 20 kg saf azot uygulamasında elde edilmiştir (*Tablo 9*).

Glüten indeksi, buğdayın glüten kalitesini ve unun işlenebilirliğini ortaya koyan önemli bir özelliktir. Glüten indeksinin yüksek olması, buğdayın güçlü bir glüten yapısına sahip olduğunu ve ekmeklik buğday olarak kullanım

potansiyelinin yüksek olduğunu gösterirken, düşük glüten indeksi değerleri zayıf glüten yapısını ve sınırlı ekmeklik özellikleri işaret eder. Çalışmada, en yüksek glüten indeksi ortalaması %78.30 ile NKU Zirve genotipinde, en düşük ise %70.27 ile dallı buğdayda tespit edilmiştir. Bu sonuçlar, genotiplerin glüten kalitesi açısından farklı performans sergilediğini ve genetik yapılarının bu farklılıkta belirleyici bir rol oynadığını göstermektedir.

NKU Zirve genotipinin glüten indeksi ortalamasının %78.30 ile en yüksek olması, bu genotipin daha güçlü bir glüten yapısına sahip olduğunu göstermektedir. Glüten indeksinin daha yüksek olması, NKU Zirve çeşidinin ekmeklik üretimi için siyez ve dallı buğdayda göre daha uygun olduğunu ortaya koymaktadır. Siyez ve Dallı buğdayın glüten indeksi ortalamasının düşük olması, bu genotiplerin zayıf bir glüten yapısına sahip olduğunu ve ekmeklik buğday olarak kullanım potansiyelinin sınırlı olduğunu göstermektedir.

### 3.5. Protein Oranı (%)

Elde edilen varyans analiz sonuçları incelendiğinde yıl, genotipler, azot dozları, genotip x sıklık interaksyonu, sıklık x azot dozu interaksyonu ve genotip x sıklık x azot dozu interaksyonu istatistiki olarak %0.01 düzeyinde önemli bulunmuştur. Genotip, tohum miktarı ve azot dozları ortalamaları ve önemlilik gruplamaları *Tablo 10*'da verilmiştir.

**Tablo 10. Genotip, tohum miktarı ve azot dozlarına göre protein oranları (%)**

*Table 10. Protein ratio (%) according to genotypes, seed amount and nitrogen doses (%)*

| Genotip   | Ortalama ve Önemlilik | Sıklık | Ortalama ve Önemlilik | Doz | Ortalama ve Önemlilik |
|-----------|-----------------------|--------|-----------------------|-----|-----------------------|
| Siyez     | 20.22 a               | 400    | 15.59                 | 10  | 15.43 b               |
| Dallı     | 14.13 b               | 450    | 16.37                 | 15  | 15.58 b               |
| NKU Zirve | 13.35 b               | 500    | 16.08                 | 20  | 16.70 a               |
|           |                       | 550    | 15.57                 |     |                       |

En yüksek protein ortalaması %20.22 ile siyez buğdayında elde edilmiş olup, bunu %14.13 ile dallı buğday ve %13.35 kg da<sup>-1</sup> ile NKU Zirve buğday çeşidi takip etmiştir. En yüksek protein oranı %16.37 ile metrekaireye 450 tohumda olurken, en düşük değer ise %15.57 ile metrekaireye 550 tohum adedinde olmuştur. Protein oranının en yüksek olduğu azot dozu ortalaması ise %16.70 ile en yüksek azot dozu olan 20 kg da<sup>-1</sup> saf azot uygulamasında olurken, en düşük değer ise %15.43 ile en düşük azot uygulaması olan 10 kg da<sup>-1</sup> tespit edilmiştir (*Tablo 10*). Genotip x tohum miktarı x azot dozları, interaksyonu ortalamaları ve önemlilik gruplamaları *Tablo 11*'de verilmiştir.

Genotip x sıklık x azot dozu interaksyonu incelendiğinde en yüksek protein değeri %22.30 ile siyez buğdayının metrekaireye 400 adedinde ve 20 kg da<sup>-1</sup> saf azot uygulamasında, NKU Zirve buğday çeşidinin en yüksek protein değeri %14.56 ile metrekaireye 400 tohum ve 20 kg da<sup>-1</sup> saf azot uygulamasında, dallı buğdayda en yüksek protein oranı %17.50 ile metrekaireye 450 tohum uygulaması ve 20 kg saf azot uygulamasında ölçülmüştür (*Tablo 11*).

Protein oranı, buğdayın besin değeri ve un kalitesi açısından en önemli parametrelerden biridir. Ünal (2002), buğdayda protein miktarının tür, çeşit ve çevre koşulları ve üretim tekniğine bağlı olarak % 6-22 arasında olduğunu ve yurdumuzda protein miktarının topbaşlarda % 9-13, ekmeklik buğdaylarda % 10-15, makarnalık buğdaylarda % 11-17 arasında değiştiğini bildirmektedir. Yüksek protein oranı, buğdayın besin değerinin yüksek olduğunu ve unun ekmeklik ürünler için daha uygun olduğunu gösterirken, düşük protein oranı buğdayın daha çok yemlik veya endüstriyel amaçlarla kullanılabileceğini göstermektedir. Yapılan değerlendirmelere göre birim alanda daha düşük bitki uygulaması ve daha yüksek saf azot uygulamasının buğday genotiplerinin protein oranının önemli oranda artırdığını ortaya koymaktadır. Siyez buğday genotipinin protein oranının yüksek olması, bu genotipin besin değeri açısından diğer genotiplere göre üstün olduğunu bu özelliği dikkate alınarak farklı amaçlar için kullanılabileceğini ortaya koymaktadır.

**Tablo 11. Genotip x tohum miktarı x azot dozu interaksyonuna göre protein oranları (%) ve önemlilikleri**

Table 11. Protein ratios (%) and their significance according to genotype x seed amount x nitrogen dose interaction

| Genotip   | Sıklık | Azot Dozu |           |           | Ortalama |
|-----------|--------|-----------|-----------|-----------|----------|
|           |        | 10        | 15        | 20        |          |
| Siyez     | 400    | 17.88 f   | 18.61 ef  | 22.30 a   | 49.62    |
|           | 450    | 21.90 ab  | 21.33 abc | 20.70 bcd | 21.31    |
|           | 500    | 21.33 abc | 20.26 cd  | 21.78 ab  | 21.12    |
|           | 550    | 18.48 ef  | 19.51 de  | 18.63 ef  | 18.87    |
| Dallı     | 400    | 13.40 g-m | 13.70 g-l | 13.86 g-l | 13.65    |
|           | 450    | 13.51 g-m | 13.71 g-l | 17.50 f   | 14.90    |
|           | 500    | 13.58 g-l | 13.18 g-m | 14.31 ghı | 13.69    |
|           | 550    | 14.15 g-k | 14.40 gh  | 14.26 g-j | 14.27    |
| NKU Zirve | 400    | 13.00 ı-m | 13.03 h-m | 14.56 g   | 13.53    |
|           | 450    | 12.16 m   | 12.68 lm  | 13.85 g-l | 12.89    |
|           | 500    | 12.90 j-m | 13.20 g-m | 14.23 g-k | 13.44    |
|           | 550    | 12.86 klm | 13.41 g-m | 14.40 gh  | 13.55    |

#### 4. Sonuç

Kültür buğdayı olan NKU Zirve ekmeklik buğday çeşidinin sedimantasyon oranı ve beklemeli sedimantasyon oranının siyez ve dallı buğday genotiplerine göre 3-3.5 kat daha yüksek olduğunu göstermektedir. Yüksek sedimantasyon değerine sahip genotiplerin ekmeklik un üretimi için tercih edilmesi, kalite ve işlenebilirlik açısından önemli bir avantaj sağlayacağı tespit edilmiştir. Dallı buğdayın düşük glüten kalitesi, bu genotipin ekmeklik buğday olarak kullanımını sınırlamakta ve daha farklı endüstriyel kullanım alanlarına uygun olduğunu göstermektedir. Ayrıca, düşük glüten kalitesi, dallı buğdayın sınırlı bir potansiyele sahip olduğunu göstermektedir. NKU Zirve ekmeklik buğday genotipinde glüten indeksinin, Dallı ve Siyez buğday genotiplerine göre %15 civarında daha yüksek olduğu ve ekmeklik üretimine daha uygun olduğu görülmektedir. Siyez buğdayı, mevcut glüten indeksi ile daha çok geleneksel ve yerel ürünlerde kullanım potansiyeline uygun olabileceği, dallı buğdayın ise mevcut glüten indeksi ile zayıf glüten yapısı ile ekmeklik buğday olarak kullanımının sınırlı olduğu ortaya çıkmaktadır. Siyez ve dallı buğday genotiplerinde yaş glüten oranı, NKU Zirve ekmeklik buğday genotipine göre daha yüksek olması hamura işlenebilirlik yönünden sorunlar oluşturabileceğini ortaya koymaktadır. Siyez buğdayında ölçülen protein oranının, NKU Zirve ekmeklik buğday genotipi ve dallı buğday genotipine göre %40-50 civarında daha yüksek çıkması besin değeri ve sağlık odaklı ürünler açısından önemli bir avantaj sağladığı söylenebilir. İncelenen kalite özellikleri farklı tohum miktarı ve saf azot oranında değerlendirdiğinde hem kültür hem de yabani buğdaylarda birim alanda daha düşük tohum miktarı uygulaması ve dekara yüksek saf azot uygulamalarının kalite özelliklerinde pozitif yönde artışa neden olduğunu ortaya koymaktadır.

#### Teşekkür

Bu çalışma birinci yazarın doktora tezinin sonuçlarının bir kısmından yararlanarak hazırlanmıştır.

#### Etik Kurul Onayı

Bu çalışma için etik kuruldan izin alınmasına gerek yoktur.

#### Çıkar Çatışması Beyanı

Makale yazarları olarak aramızda herhangi bir çıkar çatışması olmadığını beyan ederiz.

#### Yazarlık Katkı Beyanı

Planlama: Akdağoglu, M., Başer, İ.; Materyal ve Metot: Akdağoglu, M., Başer, İ.; Veri toplama ve İşleme: Akdağoglu, M., Başer, İ.; İstatistiki Analiz: Akdağoglu, M., Başer, İ.; Literatür Tarama: Akdağoglu, M., Başer, İ.; Makale Yazımı, İnceleme ve Düzenleme: Akdağoglu, M., Başer, İ.

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